Data Summary Report
EMF Site and VOC Plume Across Boeing Field

Prepared for: The Boeing Company

Prepared by: Project Performance Corporation

January 16 2002

DATA SUMMARY REPORT
EMF Site and VOC Plume Across Boeing Field

PREPARED FOR
THE BOEING COMPANY
ENERGY AND ENVIRONMENTAL AFFAIRS

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LIST OF ACRONYMS AND ABBREVIATIONS

ACLs	Alternative Cleanup Levels
ASTM	American Society for Testing and Materials
AWQC	ambient water quality criteria
bgs	below ground surface
Boeing	The Boeing Company
c12DCE	*cis*-1,2-dichloroethene
CSM	conceptual site model
DNAPL	dense nonaqueous-phase liquid
DOC	dissolved organic carbon
EAL	Environmental Analysis Laboratory
EPA	U.S. Environmental Protection Agency
FS	feasibility study
FSP	field sampling plan
GAC	granular activated carbon
ISCO	*in-situ* chemical oxidation
KCIA	King County International Airport
K_d	distribution coefficient
LOEL	lowest observed effects level
MNA	monitored natural attenuation
MTCA	Model Toxics Control Act
QA	quality assurance
RI	remedial investigation
TCE	trichloroethene
TDS	total dissolved solids
VOC	volatile organic compound

Data Summary Report: EMF Site and VOC Plume Across Boeing Field

1.0 Introduction

This document presents a summary of data collected during Remedial Investigation (RI) activities completed to date (as of October 2001) at the Electronics Manufacturing Facility (EMF) site. The EMF property is owned by King County International Airport (KCIA) and leased to The Boeing Company. The EMF site is located at Boeing Field/KCIA (Boeing Field) and is situated to the east of the active runways /taxiways and to the west of Perimeter Road forming the eastern boundary of the airfield (see Figures 1-1 and 1-2). The RI has included investigations on the EMF site along with an area impacted by a downgradient volatile organic compounds (VOC) plume in groundwater. The VOC plume extends to the west from the EMF site across Boeing Field. The initial EMF RI was conducted in 1996/1997 (Weston 1997) and additional data has been collected between 1997 and 2001 to characterize the site conditions and the downgradient VOC plume in groundwater.

This section of the report presents introductory information, including general site background information. Section 2.0 presents general information on site conditions. Field activities that were conducted during the RI and remediation phases are described in Section 3.0. Sections 4.0 and 5.0 present a summary and evaluation of the data collected.

1.1 Background

Past activities at the EMF site resulted in releases of trichloroethene (TCE), a chlorinated industrial solvent, to the ground. These releases resulted in contamination of groundwater at the EMF site. The VOC plume in groundwater (associated with the EMF site) extends in a westerly direction across the active runways and taxiways of Boeing Field. The VOC plume has been transported by the natural groundwater flow to the southwest direction towards the Duwamish Waterway.

The EMF site has been the subject of past investigations and remedial actions. Groundwater investigations conducted at the EMF site indicated that TCE downgradient of the source area was undergoing natural attenuation. Evidence of natural attenuation included the presence of a static plume (i.e., contaminant isopleths were not advancing downgradient), as well as the presence of TCE degradation products. Because natural attenuation of TCE was occurring, the remedial approach selected for the EMF site was active treatment of the concentrated source area coupled with monitored natural attenuation (MNA). Based on existing data and evaluations, natural attenuation was expected to reduce contaminant concentrations to cleanup standards before the groundwater discharges to the Duwamish Waterway.

Groundwater at and downgradient of the EMF site is not a source of potable water. Therefore, groundwater cleanup standards have been based on protection of surface water and were set equal to ambient water quality criteria (AWQC).

In 1997, a groundwater remediation system was installed at the EMF site. This system consisted of two recirculating wells that were operated to recover dissolved TCE from the aquifer. One of the wells recovered a limited quantity of TCE as dense, nonaqueous-phase liquid (DNAPL). Operation of this system resulted in removal of approximately 1,800 pounds of TCE from the aquifer.

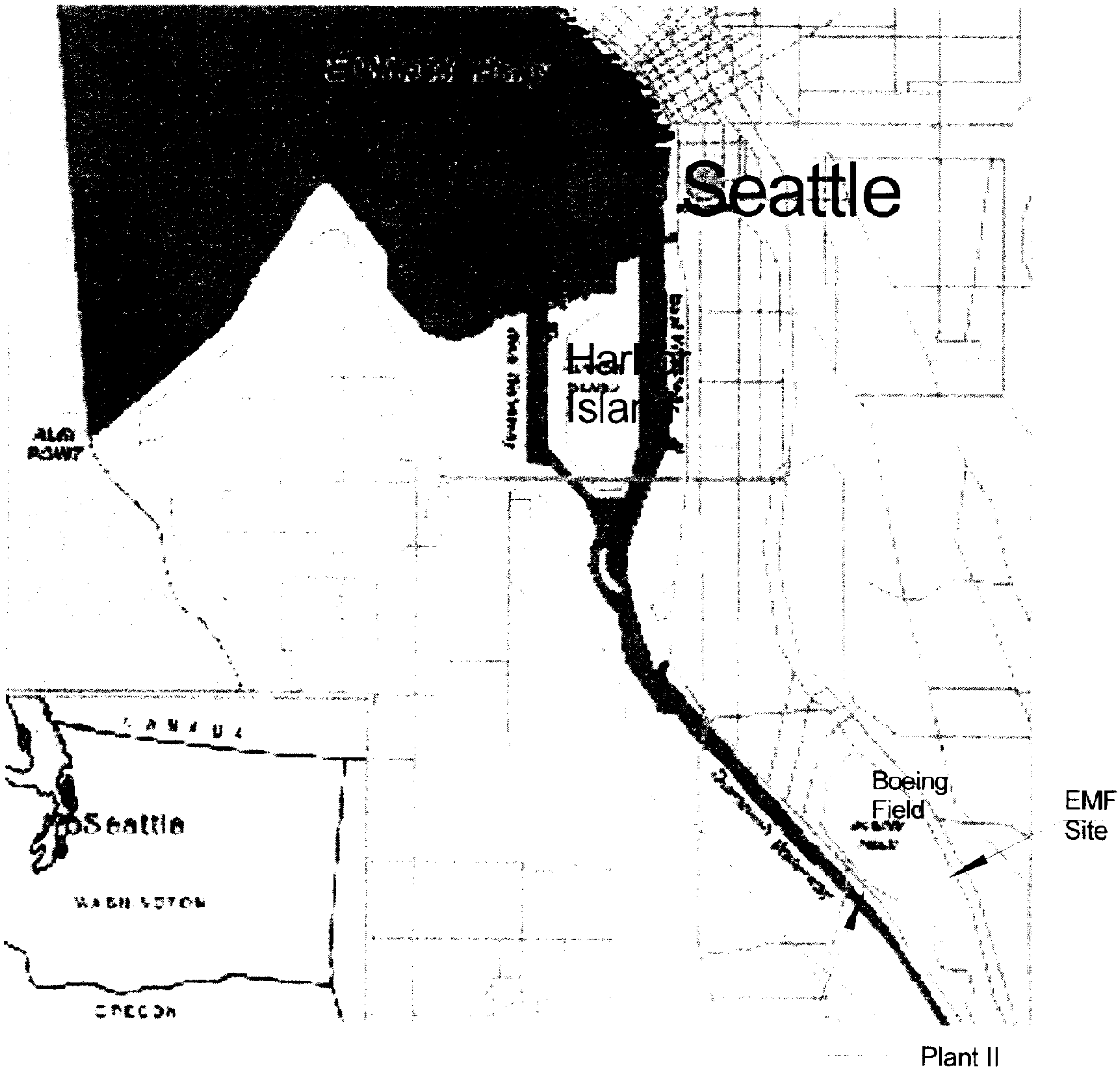


Figure 1-1. Site Location Map
(EMF Site, Boeing Field, Plant II)

KCSlip4 43913

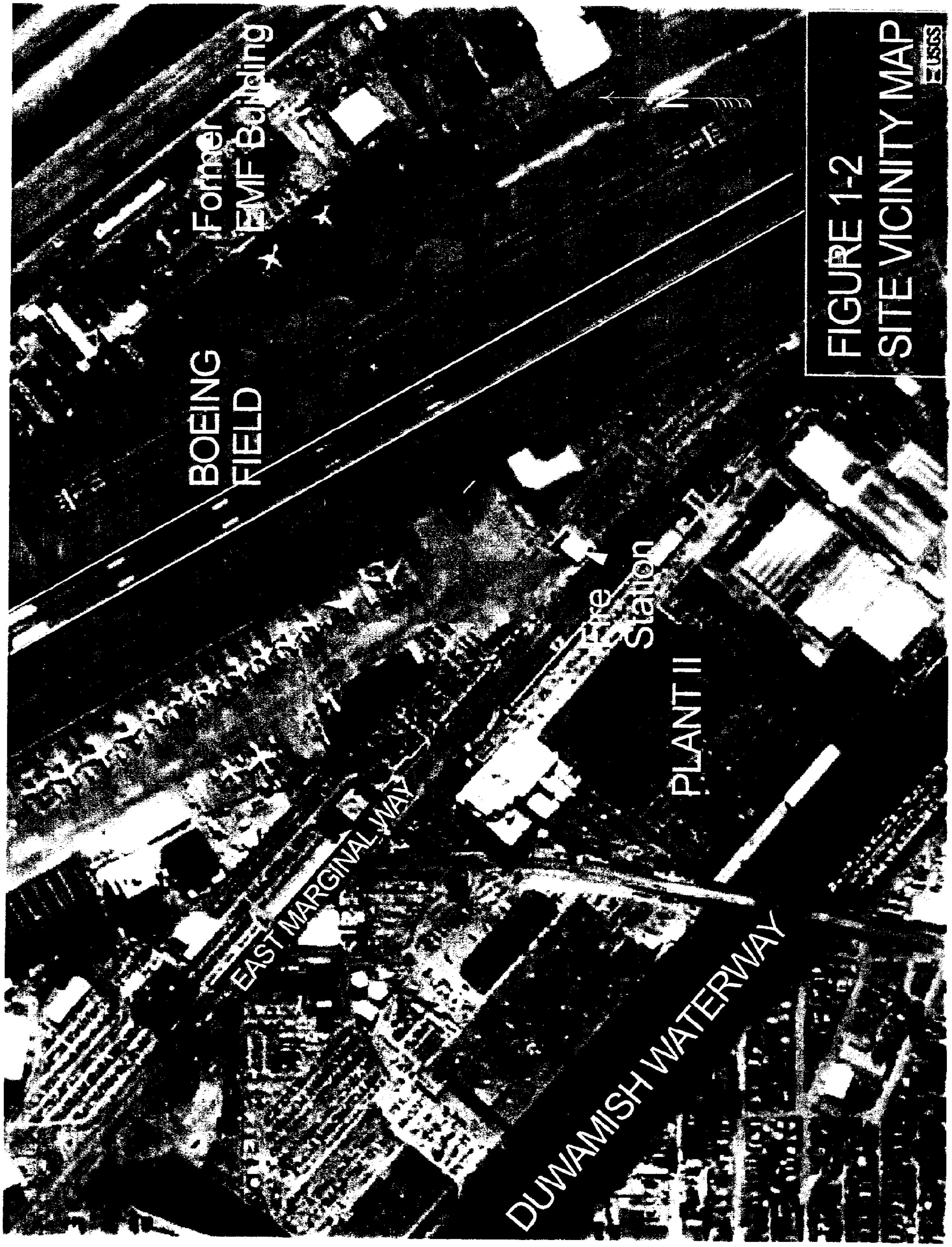


FIGURE 1-2
SITE VICINITY MAP
USGS
Former
EMF Building
BOEING
FIELD
Fire
Station
PLANT II
EAST MARGINAL WAY
DUWAMISH WATERWAY
N

Although this system has been effective in removing a large mass of contaminant, a significant mass of contaminant remained at the site, primarily in the area downgradient of the zone treated by the initial remediation system installed . As a result, Boeing began implementation of in-situ chemical oxidation (ISCO) at the site in Spring 2000. The ISCO treatment has consisting of in-situ destruction of VOCs using permanganate and peroxydisulfate. This approach was successfully demonstrated at a pilot scale and full-scale implementation began in 2000 and continued during 2001.

1.2 Objectives of Added Remedial Investigation Activities

In 1999 data was collected that indicated the VOC plume was larger than originally thought in the 1997 RI/FS report. The new data required a revision to the conceptual model of site conditions and the planned approach to remedial action. In 2000 and 2001, Boeing implemented additional phases of investigations downgradient of the EMF site. The objectives of these added investigations were to:

1) Define the VOC plume limits;

2) Provide downgradient monitoring points to provide proof/verification that MNA is an effective part of the remedial strategy at the site;

3) Determine hydraulic conductivity, transmissivity, and groundwater velocity; and

4) Collect data to verify and demonstrate that VOCs from the site are not reaching the Duwamish Waterway at levels in excess of the site cleanup standards (water quality criteria for protection of fish).

Treatment of groundwater at locations between the EMF site and the west side of Boeing Field is not practical because of the access constraints posed by the active runways and taxiways of the airport. As a result, most of the additional investigations (plume delineation, aquifer pumping test) have been focused in the area near the west side of Boeing Field (some investigations have been implemented in the center of Boeing Field). Section 3.0 describes the specific field investigation activities that have been implemented.

2.0 Site Conditions

This section presents descriptions of site conditions. Section 2.1 presents general site conditions. Sections 2.2 through 2.4 address specific site characteristics. Many of these conditions have been characterized by the previous RI for the EMF site. As appropriate, the results of prior investigations at the EMF site are summarized in this section. Where required information was not available from previous investigations, additional data were obtained from the follow-on RI activities described in this report.

A conceptual site model (CSM) identifying sources of hazardous substances, pathways for contaminant migration, and potential receptors is shown in Figure 2-1. The information used to develop this CSM, and interpretations/conclusions drawn from this CSM, are presented in the following sections.

2.1 General Site Conditions

This section presents a summary of site conditions, an aerial photograph of the site and immediate surrounding area is presented in Figure 1-2. The EMF site consists of that portion of the Boeing Field impacted by the EMF plume that is located in a west to southwest direction of the former EMF facility.

Most of the area is paved and served by a storm water collection and conveyance system, the exceptions are the grassy strips between the runways. The buildings in the area near the EMF site include the south end of the KCIA arrivals building. On the west side of Boeing Field the buildings include the Fire Station, a guard station at the gate and several smaller flight delivery structures. Utilities present in the area include storm water collection and piping, water supply, sanitary sewer, and electric service. The property on the west side of Boeing Field is bounded to the southwest by East Marginal Way which contains numerous utilities (gas, electric, water, stormwater, and sanitary sewer).

2.2 Surface Water and Sediments

The nearest surface water body to the EMF site is the Duwamish Waterway, which is located approximately 3,700 ft to the southwest of the site (~ 1,600 ft from the west side of Boeing Field). Activities at the EMF site are not expected to result in impacts to surface water or sediments in the Duwamish Waterway. The site is part of an active airport facility and surfaces are paved. Thus, there are no natural drainage patterns or areas of erosion or sediment deposition on site. Precipitation falling on the site is collected by on-site storm sewers that discharge to the Duwamish Waterway.

As shown in the CSM, potential impacts to surface water are related to the fact that shallow groundwater in the vicinity of the EMF site discharges to the Duwamish Waterway. As will be described in more detail in Section 2.4, VOCs have been detected in groundwater beneath the site at levels in excess of AWQCs. As a result, these contaminants have the potential to adversely impact surface water unless concentrations are reduced (by natural attenuation or other means) before reaching the river. Consequently, cleanup standards for the groundwater contamination at the site have been based upon protection of surface water quality.

Because groundwater cleanup standards are based on protection of surface water and there are no other discharges of contaminants to surface water from the site, surface water and sediment quality have not been specifically addressed in the field investigations.

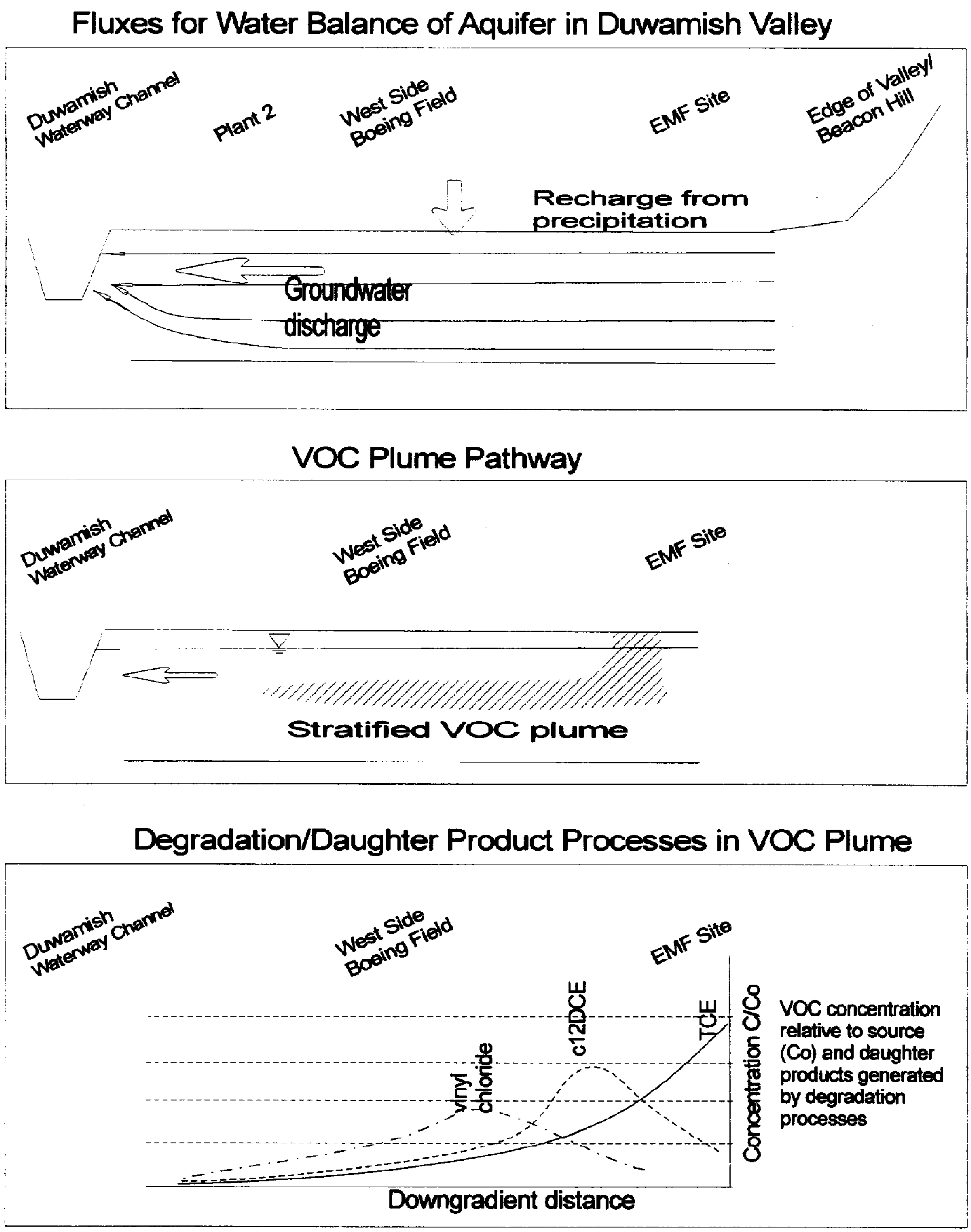


Figure 2-1 Conceptual Site Model
EMF Site and VOC Plume

2.3 Soils

The EMF site is located in the Duwamish valley. The Duwamish Waterway was dredged to its present course in the early 1900s and the ancestral channel and tideflat areas were filled with materials sluiced from the present day channel, as well as nearby upland areas. Based on logs of numerous boring in the area, the hydraulic fill material appears to be nearly homogeneous at different spatial locations, although some vertical layering is present.

Sampling data has demonstrated that vadose zone soils at the EMF site (and in downgradient directions) are not contaminated. As shown in the CSM, VOCs have migrated from the EMF site by means of a stratified groundwater plume. As a result, VOCs are present in the saturated zone and have not impacted the vadose zone. The field screening of soil samples (organic vapor analyzer readings from soil cores) and lab analysis of soil samples indicate that the vadose zone soils have not been impacted.

2.4 Geology and Groundwater System

Data describing the geology and groundwater system in the vicinity of the EMF site were originally collected during performance of the RI for the EMF site. Additional information was collected during subsequent investigations related to installation of the groundwater treatment systems at the EMF site and in investigations in the downgradient areas. This information is briefly summarized below. Additional information collected as part of the RI and aquifer pumping test for the downgradient plume area is then presented.

2.4.1 Stratigraphy

EMF Site. The stratigraphy at the site was generally described in the RI for the EMF site as intermittent fill underlain by a sand alluvium to a depth of about 30 to 40 feet below ground surface (bgs). The base of the sandy alluvium reportedly graded to a finer sand with a silt zone in the bottom 5 to 10 feet (an interval located approximately 30 to 40 ft bgs). The sandy alluvium was reportedly underlain by a silty-clay zone having an approximate thicknesses of 5 to 10 feet encountered at a depth of about 40 to 45 ft bgs. The silty-clay unit was encountered in all three borings advanced to this depth at the site during the EMF RI, and water samples collected beneath this zone contained no detectable VOCs. Core samples collected from the silty clay zone reportedly indicated an approximate hydraulic conductivity of 3×10^{-7} cm/sec, thus indicating that this layer is an aquitard and provides an effective barrier to vertical plume movement.

The geologic cross section prepared for the EMF RI indicated a localized lens of low permeability soil near the eastern boundary of the site (from geologic boring SB-24) with more permeable sands above and below the lens. This is consistent with the observations made to the west where recirculating wells were installed, but the depth interval where the upper silty layer was encountered is slightly deeper, consistent with a downward dip toward the west.

Downgradient plume areas. Stratigraphy in the downgradient plume area has been determined from borings completed after the RI. The general stratigraphy in the area near the west side of Boeing Field is as follows. The surface consists of concrete and tarmac, which is underlain by varying depths of fill. The fill is underlain by a silty zone, which extends to a depth of approximately 15 to 20 ft bgs. Materials in this zone appear to consist of approximately 50% fines (i.e., silt- and clay-sized particles). This zone is underlain by uniform fine to medium sands, which extend to a depth of approximately 50 ft bgs. Based on particle-size analyses of samples collected from this zone, this material contains approximately 1% fines. This zone is then underlain by interbedded sands and silts. A cross section showing the stratigraphy encountered in the monitoring wells placed along the west side of the Boeing Field is shown in Figure 2-2. The locations of these wells are shown in Figure 2-3. Boring logs for the borings installed after the EMF RI and for the pump test are included in Appendix A. The stratigraphy described above is equivalent with the results of two previous geotechnical investigations conducted in the immediate area.

As noted above, samples of material from the sandy aquifer zone were collected at the from borings on the western side of Boeing Field and analyzed for particle-size distribution. The results of these analyses are presented in Appendix B.

2.4.2 Groundwater Flow

The general direction of groundwater flow at the site is towards the Duwamish Waterway. The groundwater gradient at the EMF site has previously been mapped based on surveyed well head elevations and depth to water measurements in wet and dry seasons. Two figures depicting the direction of the gradient in wet and dry seasons are shown in Figures 2-4 and 2-5. The expected flow direction based the regional groundwater flow pattern is shown in Figure 2-6. This figure is based on the expectation that the average groundwater flow direction should be generally perpendicular to the discharge zone along the Duwamish Waterway.

Based on the results of previous investigations, ancestral river channels are present in the Duwamish Valley, including one at the western edge of the EMF site. The data collected in this RI indicates that the VOC plume follows the regional groundwater flow direction (essentially an unchanged path) as it passes over the ancestral river channel. Based on available data, the presence of this channel does not appear to affect the direction of groundwater flow or the general VOC plume migration direction.

As described in Section 2.4.1, a low permeability lens was observed near the bottom of the aquifer at the EMF site and appeared to divide the aquifer into upper and intermediate zones. Water level data collected after the EMF RI indicated some hydraulic separation between the upper zone and the intermediate zone based on piezometric data from well pairs MW-1D/MW-1S and MW-3D/MW-3S; these data are presented in Table 2-1. Near wells MW-1 and MW-3, which are at the EMF site, the site data indicate a water level difference between the shallow and intermediate zones of approximately 1 foot with a downward gradient. These data indicate the presence of a restrictive layer that causes the water level difference. Down gradient from the site (near the EMF lease property boundary) near well pair MW-11D/MW11-S, the water level difference apparently disappears between the shallow and intermediate zones.

The hydraulic conductivity of the aquifer where the VOC plume is present near the western side of Boeing Field was determined from an aquifer pumping test conducted in September 2001. The aquifer pumping test is presented in Appendix C and indicates a hydraulic conductivity in the range of 400 feet/day (1.4x 10^{-1} cm/sec). Data collected back at the EMF site indicate a hydraulic conductivity that is lower relative to the measured value on the west side of Boeing Field (based on soil texture and grain size distributions).

Groundwater elevations measured in wells installed near the west side of Boeing Field are shown in Figure 2-7. Based on these elevations, the hydraulic gradient in this area (i.e., by the fire station on the west side of North Boeing Field) is 0.0011 ft/ft.

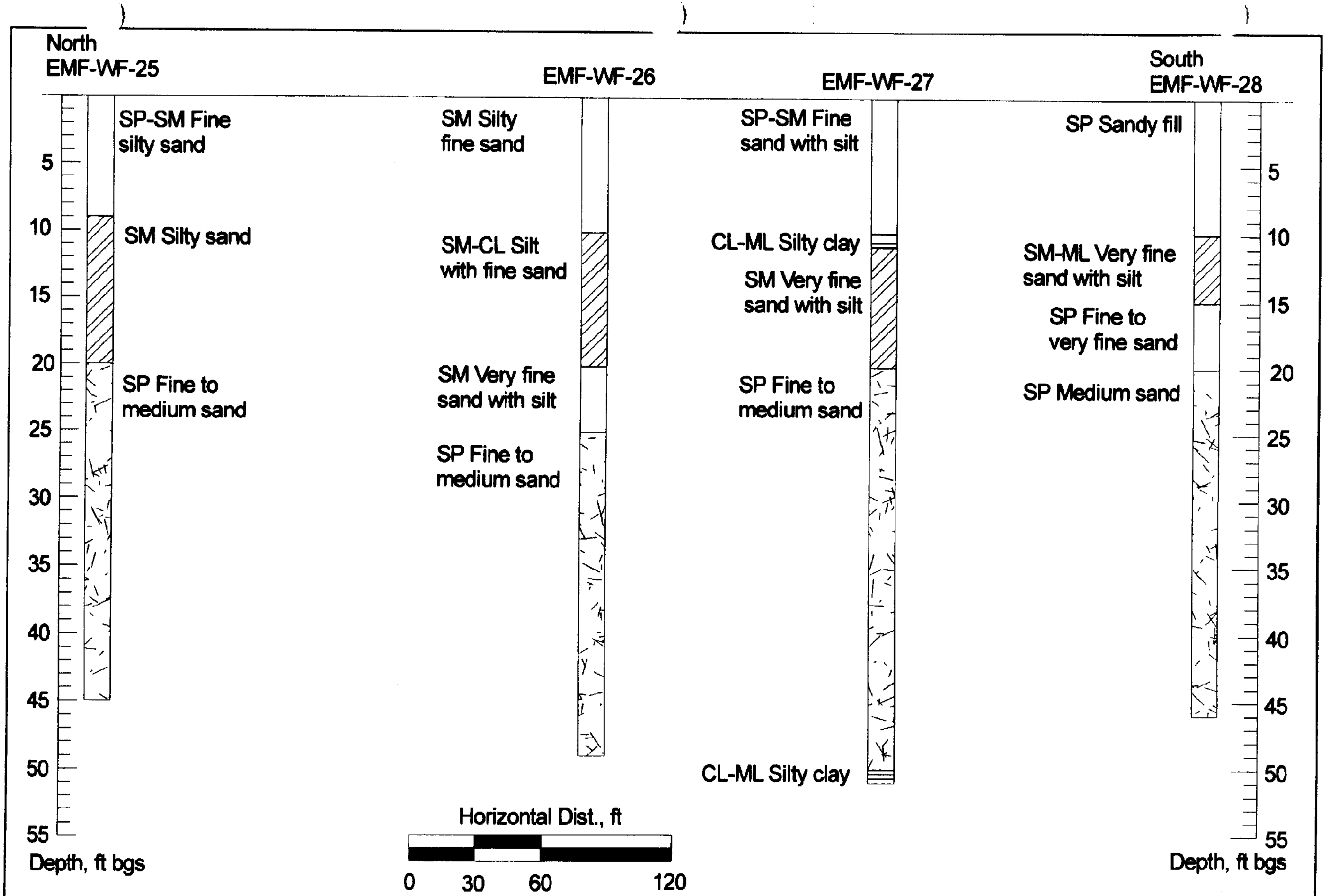
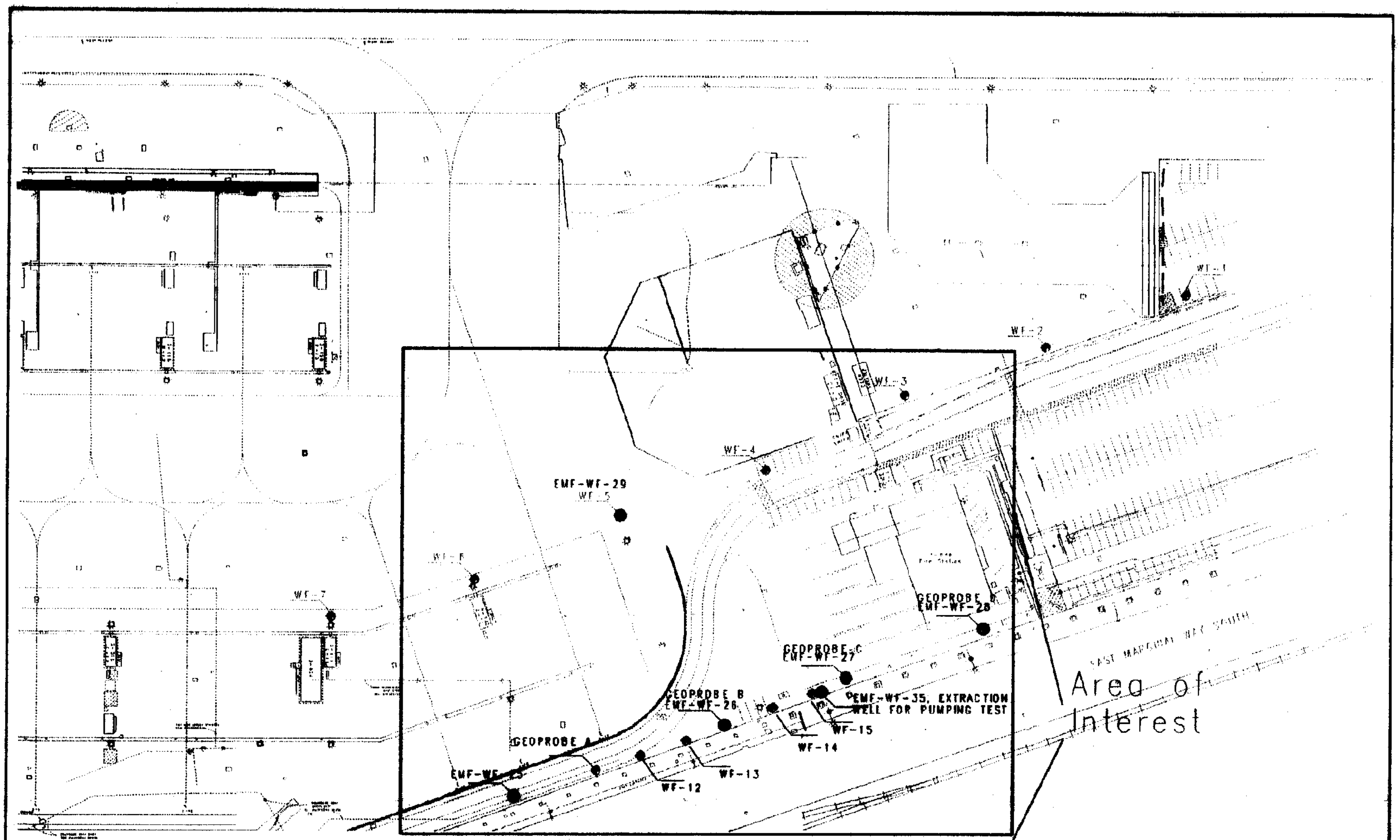


Figure 2-2. Cross Section Showing Stratigraphy in Borings Across West Side of North Boeing Field.



LEGEND
Geoprobe Sampling Location
Monitoring well location

Figure 2-3. Sampling Locations in EMF Plume, West Side of North Boeing Field

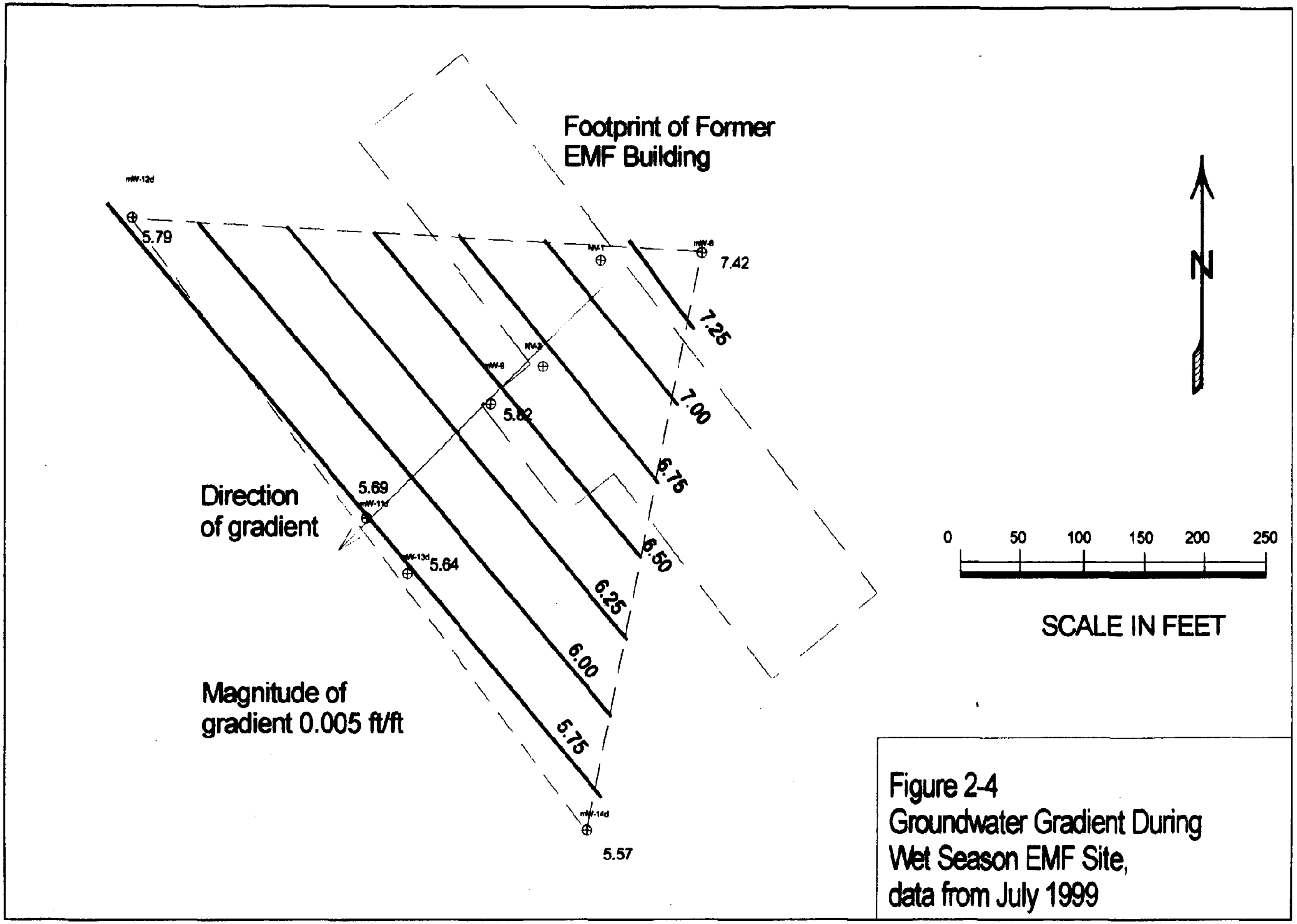


Figure 2-4
Groundwater Gradient During
Wet Season EMF Site,
data from July 1999

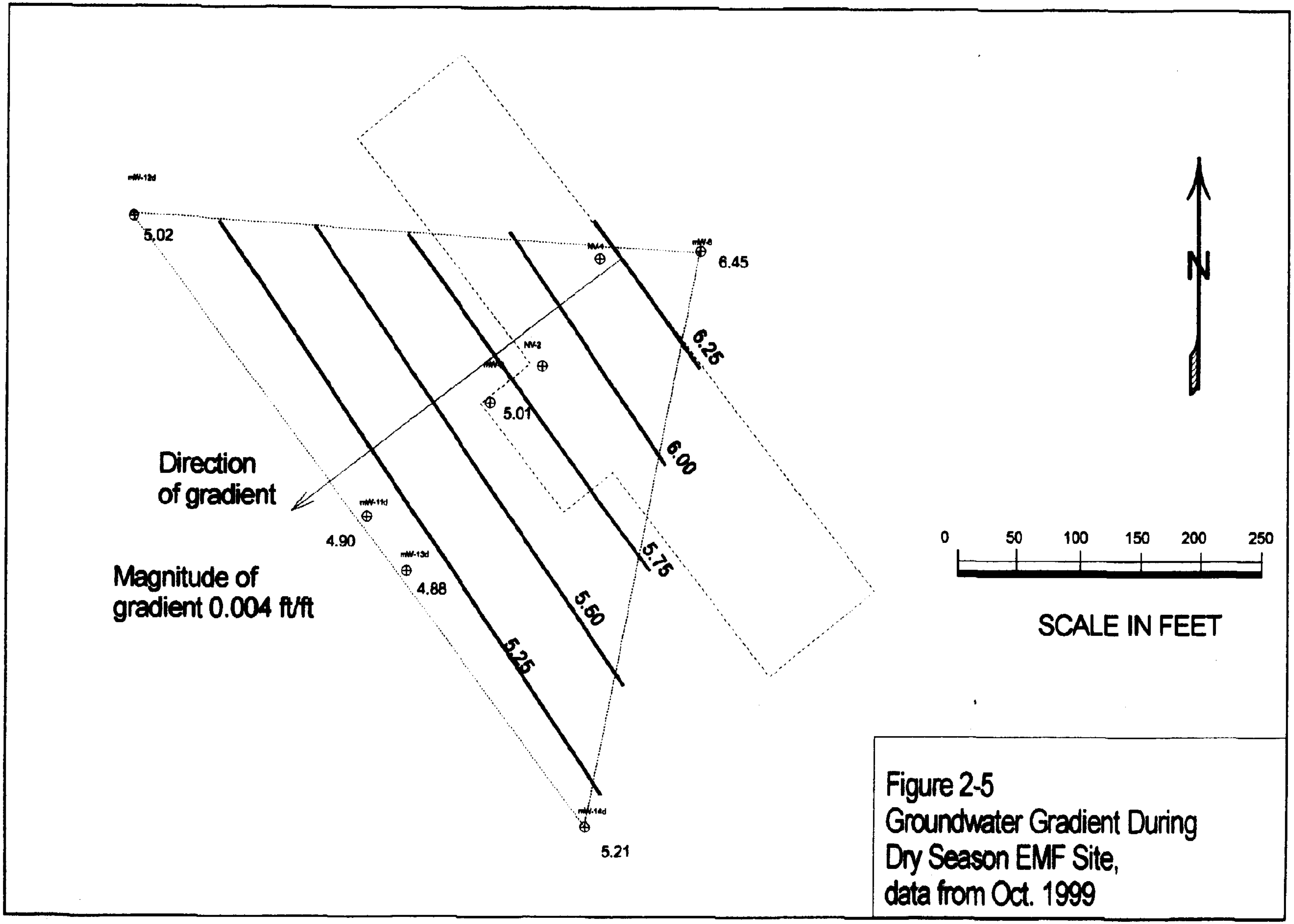


Figure 2-5
Groundwater Gradient During Dry Season EMF Site, data from Oct. 1999

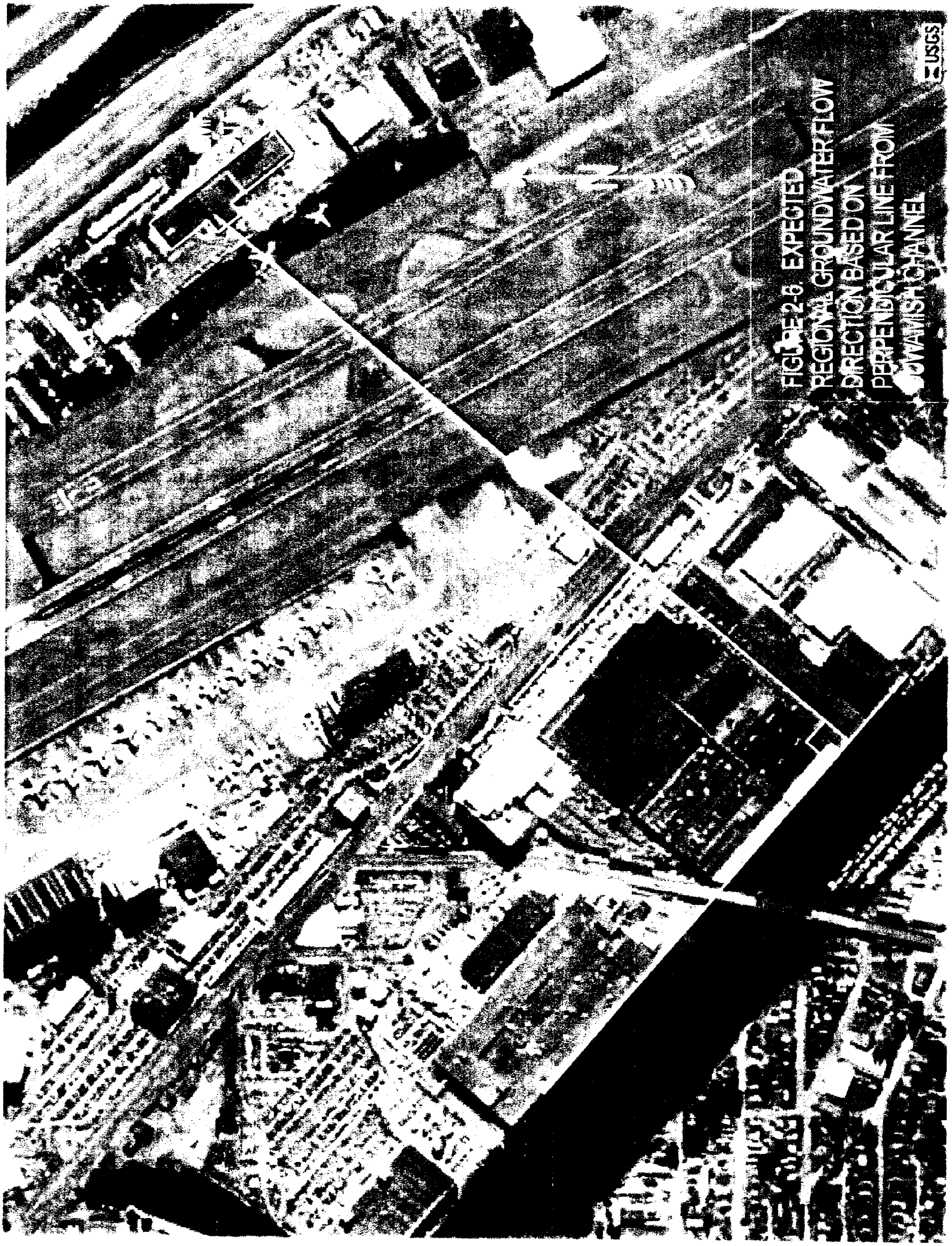
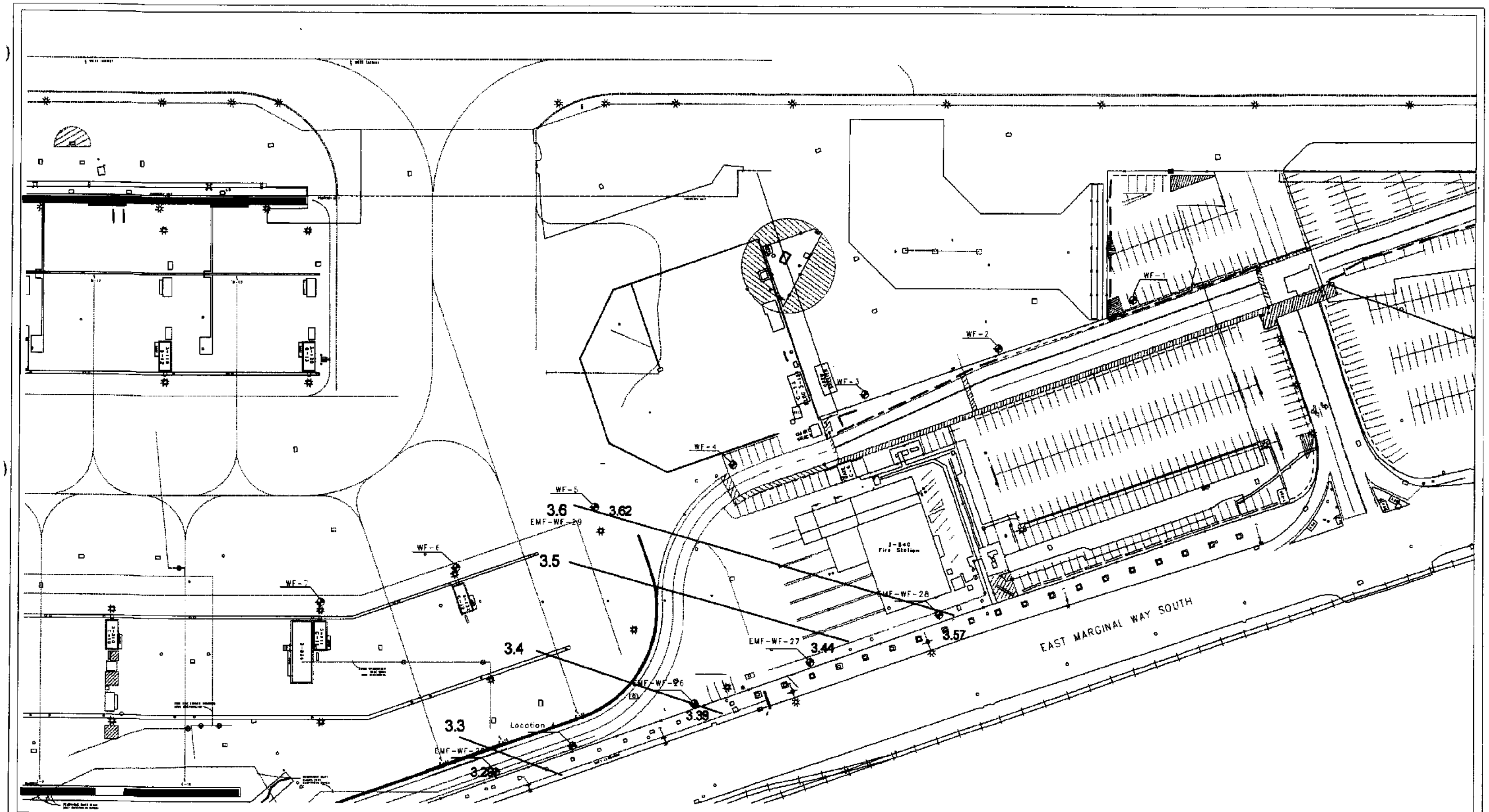


FIGURE 2-6. EXPECTED
REGIONAL GROUNDWATER FLOW
DIRECTION BASED ON
PERPENDICULAR LINE FROM
DUWAMISH CHANNEL
USGS



BOEING

LEGEND

Well/Geoprobe Locations

40' 20' 0 40' 80'
APPROXIMATE SCALE IN FEET

KEY PLAN

Figure 2-7. GROUNDWATER GRADIENT
WEST SIDE OF NORTH BOEING FIELD

This gradient and the measured hydraulic conductivity results in a groundwater pore velocity in the range of 600 feet/year, assuming an effective porosity of 0.25. This estimate of groundwater velocity is generally consistent with the observed length and estimated age of the contaminant plume. The average groundwater gradient calculated from the EMF site across Boeing Field is 0.002 ft/ft.

Table 2-1. Water Level Measurements From Well Pairs at EMF Site.

	11/18/98	1/25/99	4/20/99	7/28/99	10/19/99
Well ID	**Water level elevation, feet NVGD29**				
EMF-MW-1S	6.35	8.71	8.43	7.18	6.29
EMF-MW-1D	5.23	7.83	7.18	5.92	5.22
EMF-MW-3S	6.35	8.71	nt	nt	nt
EMF-MW-3D	5.26	7.82	nt	nt	nt
EMF-MW-11S	5.16	7.83	7.03	5.69	4.92
EMF-MW-11D	5.14	7.83	7.02	5.69	4.90

2.4.3 Groundwater Quality

The following sections provide short synopsis of the groundwater quality data. The majority of the water quality data and interpretation are presented in sections 4 and 5.

2.4.3.1 EMF RI

The initial interpretation presented in the 1997 EMF RI was that the highest levels of VOCs (TCE and degradation byproducts *cis*-1,2-dichloroethene [cis1,2-DCE] and vinyl chloride) were encountered in the depth interval from 8 to 25 ft bgs. The size of the VOC plume was estimated at a diameter of about 100 feet to the extent where AWQCs would be met and about 300 feet to a diameter where maximum contaminant levels (MCLs) would be met.

2.4.3.2 Subsequent Groundwater Investigations

Quarterly groundwater sampling has been completed at the on-site EMF wells since 1997. A summary of the quarterly monitoring data is included in Appendix D The objective of this report is to summarize the additional investigations completed (VOC plume and geological characterization, Geoprobe investigations, well installations, pumping test, etc.). The revised interpretation of the VOC plume is presented with the summary of laboratory results in Section 4.

3.0 Field Investigations and Sampling

This section identifies specific field activities undertaken during the additional EMF RI. Because the downgradient extent of contaminant migration was unknown and access to potential sampling locations was limited (in some areas), the field investigation was conducted in multiple phases. The first phase involved collection of samples at the downgradient edge of the EMF lease property. Based on positive detection of contaminants above cleanup standards at this location, the basic conceptual model of the site geology and VOC plume extent was revised. Multiple field investigations in the onsite area and downgradient VOC plume area were subsequently implemented. The field activities conducted during these six phases are described below.

3.1 Phase 1 Sampling

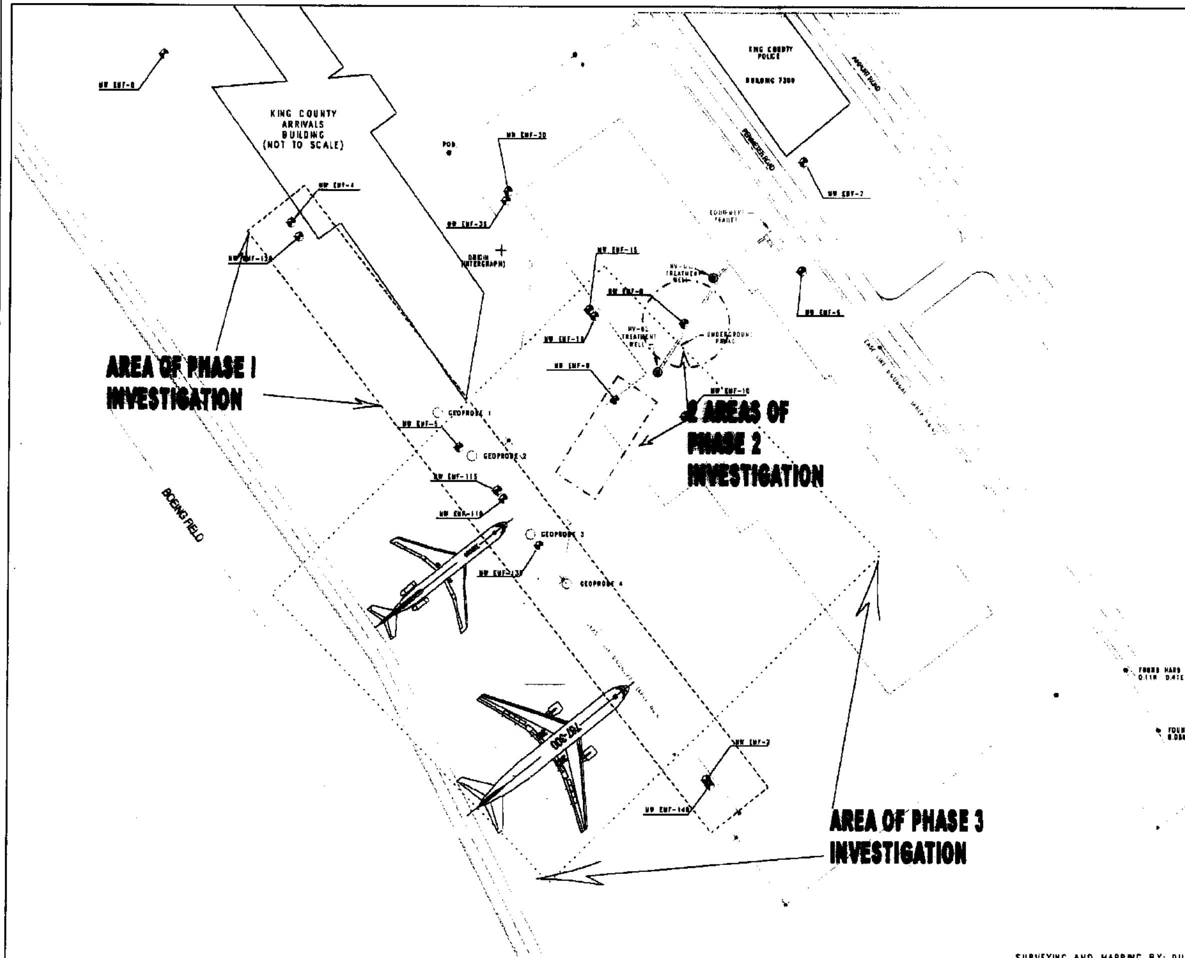
Phase 1 sampling activities involved collection of groundwater samples at locations near the western edge of the EMF lease property. These samples were collected to define the presence and the horizontal/vertical extent of a VOC plume at this downgradient property boundary. Water samples were initially collected from four locations with multiple samples collected over the vertical profile to a depth of ~ 50 ft bgs. The sampling locations (designated GP-1, GP-2, GP-3, GP-4) are shown in Figure 3-1. Following review of the analytical results multiple monitoring wells were installed in this area (MW-11D, MW-11S and MW-13D in the central area of the plume and MW-12D and MW-14D near the northern and southern plume boundaries).

The wells were installed in boreholes drilled using 8-¼-inch outside diameter hollow-stem augers. Samples of aquifer materials were collected at approximately 5-ft intervals below the water table using a split spoon sampler. Monitoring wells were constructed inside the hollow-stem augers. Each well was installed with a 10-ft screened interval, with screen consisting of 2-in. diameter 0.010-in. factory-slotted polyvinyl chloride (PVC) screen. An end cap was installed on the bottom of each screen. The well casing above the screens consisted of 2-in. diameter schedule 40 PVC. The wells were completed below grade with the well heads located inside flush-mount surface monuments. A locking screw-plug well cap was installed in each well. Each of these new wells installed was surveyed to identify the horizontal coordinates and top of casing elevation.

Groundwater samples were submitted for laboratory analysis of VOCs using U.S. Environmental Protection Agency (EPA) Method 8260b. Samples for VOC analysis were collected in 40-mL glass septum-top vials with no headspace, acidified with hydrochloric acid, and preserved by cooling to 4 °C or less. Samples were analyzed at the Boeing Environmental Analysis Laboratory (EAL) ,a laboratory accredited by Ecology.

3.2 Phase 2 Sampling

Phase 2 sampling activities involved collection of groundwater samples at locations on the EMF lease property focused initially near the suspected TCE release and then including additional downgradient samples . These samples were collected to define the horizontal/vertical extent of a VOC plume in this area. Water samples were initially collected from 10 locations near the TCE source (multiple samples collected over the vertical profile to a depth of ~ 45 ft bgs). The general area of the Phase 2 sampling is marked in Figure 3-1 and the sampling locations are shown in Figure 3-2. All of the sampling in this phase was completed using a Geoprobe rig.



MONITOR WELL NO.	STAMPED	ELEV. TOP WELL	ELEV. TOP CASE	NORTHING	EASTING
EMF-6	NOT STAMPED	15.05	15.34	[illegible]	1,277,778
EMF-3D	NOT STAMPED	14.43	14.69	100,063	1,277,508
EMF-3S	NOT STAMPED	14.43	14.66	100,045	1,277,504
EMF-1S	NOT STAMPED	14.68	15.09	100,046	1,277,562
EMF-1D	NOT STAMPED	14.75	15.07	100,040	1,277,567
EMF-2	NOT STAMPED	13.46	13.69	100,315	1,277,602
EMF-5	NOT STAMPED	13.72	13.67	100,510	1,277,462
EMF-4	NOT STAMPED	13.93	14.24	101,024	1,277,304
EMF-7	NOT STAMPED	16.69	17.06	101,189	1,277,618
EMF-8	NOT STAMPED	14.53	14.85	100,443	1,277,579
EMF-9	NOT STAMPED	13.96	14.50	100,063	1,277,507
EMF-10	NOT STAMPED	14.44	14.73	100,048	1,277,471
EMF-11S	NOT STAMPED	13.50	13.96	100,778	1,277,497
EMF-11D	NOT STAMPED	13.51	13.97	100,772	1,277,503
EMF-12D	NOT STAMPED	13.87	14.18	101,011	1,277,311
EMF-13D	NOT STAMPED	13.71	14.18	100,730	1,277,536
EMF-14D	NOT STAMPED	13.43	13.81	100,522	1,277,686
HV-01	NOT STAMPED		14.83	100,075	1,277,606
HV-02	NOT STAMPED		14.81	100,060	1,277,648

ELEVATIONS WERE TAKEN ON THE NORTH RIM FOR BOTH TOP OF CASE AND TOP OF WELL

NOTES :
BUILDING FOOTPRINT SHOWN HEREON IS BASED FROM THE LOCATION OF THE EXISTING E.M.F FOUNDATION AS MAPPED BY DHA ASSOCIATES, INC. IN MAY 1995. FOUNDATION MAPPING OCCURRED AFTER THE DEMOLITION OF THE E.M.F. BUILDING.

ORIGIN (INTERGRAPH)
X 1,277,500
Y 100,000

LEASE AREA No. 5
LEASE LINE SHOWN HEREON IS APPROXIMATE ONLY

SURVEYING AND MAPPING BY: DUANE HARTMAN AND ASSOCIATES, INC

REVISION	BY	DATE
ADDED APPROXIMATE LEASE LINE BOUNDARY	DAH	03/15/95
ADDED WELLS EMF-8 THROUGH EMF-11D	CDB	03/02/95
ADDED WELLS 12 THROUGH 14	CDB	06/26/95
PROPERTY CORNER STAKEOUT & WELL TIES	CDB	08/02/95

BOEING

FIGURE 3-1

LOCATION OF ON-SITE INVESTIGATION AREAS (PHASE 1,2,3), EMF SITE

DHA JOB No.839.00

KCSlip4 43928

SEA410458

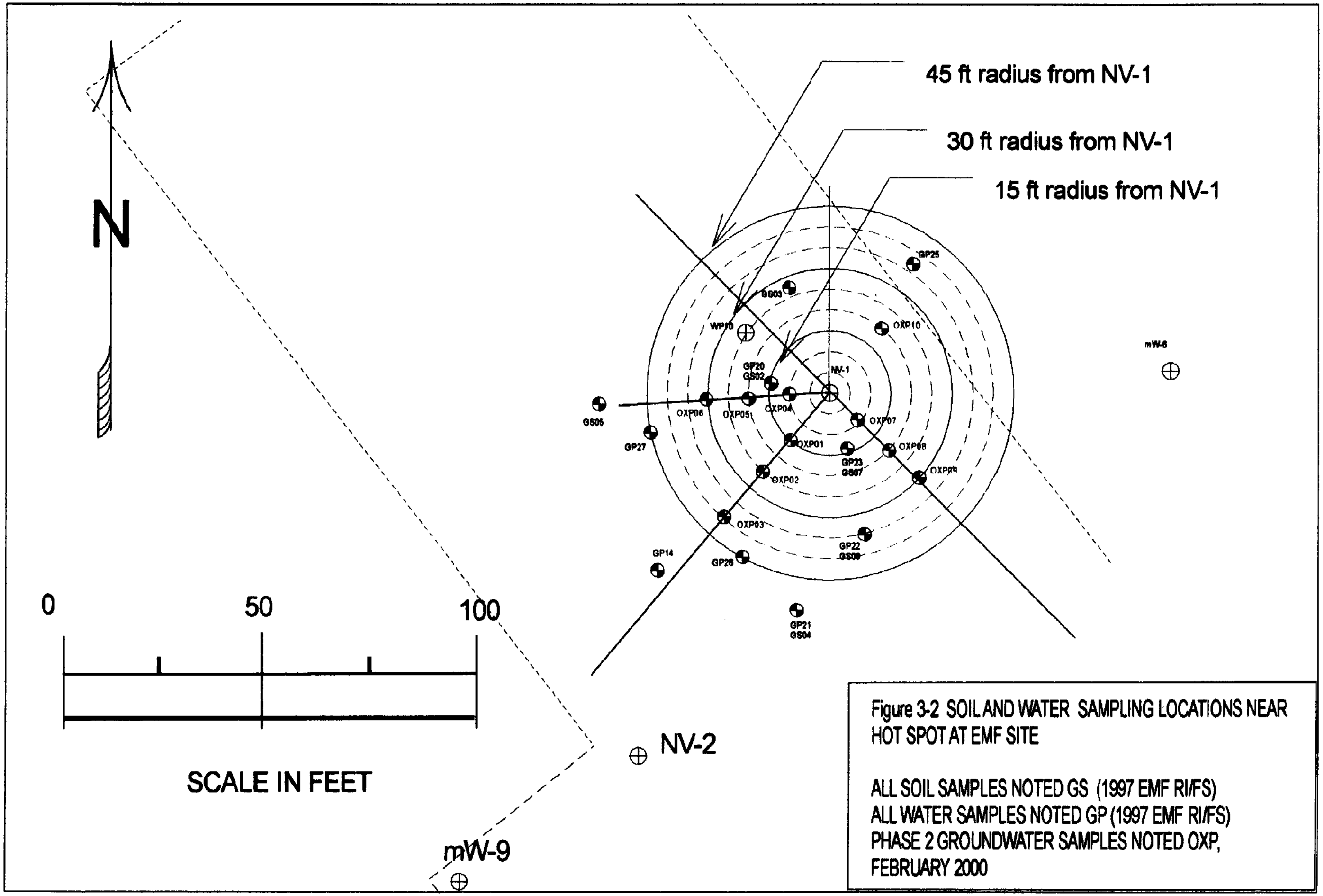


Figure 3-2 SOIL AND WATER SAMPLING LOCATIONS NEAR HOT SPOT AT EMF SITE

ALL SOIL SAMPLES NOTED GS (1997 EMF RI/FS)
ALL WATER SAMPLES NOTED GP (1997 EMF RI/FS)
PHASE 2 GROUNDWATER SAMPLES NOTED OXP, FEBRUARY 2000

Groundwater samples were submitted for laboratory analysis of VOCs using EPA Method 8260b. Samples for VOC analysis were collected in 40-mL glass septum-top vials with no headspace, acidified with hydrochloric acid, and preserved by cooling to 4 °C or less. Samples were analyzed at the Boeing EAL.

3.3 Phase 3 Sampling

Phase 3 sampling activities involved collection of groundwater samples at additional locations on the EMF lease to define the extent of the on-site VOC plume. These samples were collected using a Geoprobe rig with multiple samples over depth. Water samples were collected to define the areas where source control would subsequently be implemented. The general area of the Phase 3 sampling locations are shown in Figure 3-1. The sampling in the phase of the investigations was focused on water samples from a depth of about 25 to 45.

Groundwater samples were submitted for laboratory analysis of VOCs using EPA Method 8260b. Samples for VOC analysis were collected in 40-mL glass septum-top vials with no headspace, acidified with hydrochloric acid, and preserved by cooling to 4 °C or less. Samples were analyzed at the Boeing EAL.

3.4 Phase 4 Sampling

Phase 4 sampling activities involved collection of groundwater samples at locations within the grassy strip between the two runways at Boeing Field/KCIA. These samples were collected to define the horizontal extent (i.e., width) of the plume crossing the grassy strip, as well as the vertical distribution of contaminants in the aquifer beneath the grassy strip. Samples were collected from six locations, shown in Figure 3-3. A Geoprobe rig was used to collect these samples. Previous sampling east of this location (from the prior phases of investigation) had shown the plume to be stratified at an interval between 35 and 45 ft bgs. Based on this information, samples were collected beginning at a depth of 30 ft bgs. Samples were then collected at approximate 10 ft intervals until the low permeability layer underlying the aquifer was encountered. Three samples were collected at each location. These samples were collected at depths of 30 ft, 40 ft, and 45 or 47 ft, depending on site stratigraphy.

Groundwater samples collected using the Geoprobe rig were analyzed for VOCs and chloride ions. VOC analysis was performed to determine the concentrations of TCE and degradation products in groundwater at various depths and locations. Chloride analysis was performed to determine concentrations of chloride, which is a byproduct of reductive dechlorination, believed to be the principle degradation mechanism of TCE in groundwater at the site.

Groundwater samples were submitted for laboratory analysis of VOCs using EPA Method 8260b and chloride ions using EPA Method 300.0. Samples for VOC analysis were collected in 40-mL glass septum-top vials with no headspace, acidified with hydrochloric acid, and preserved by cooling to 4 °C or less. Samples for chloride ion analysis were collected in 500-mL polyethylene bottles. Samples were analyzed at the Boeing EAL

This sampling was completed in November 2000. Field work in this active runway area required closing of the airport and therefore only Geoprobe samples were collected (no wells were installed due to the access restrictions). The sampling was completed over a series of the 3 nights (the airport could only be closed for a few hours each night).

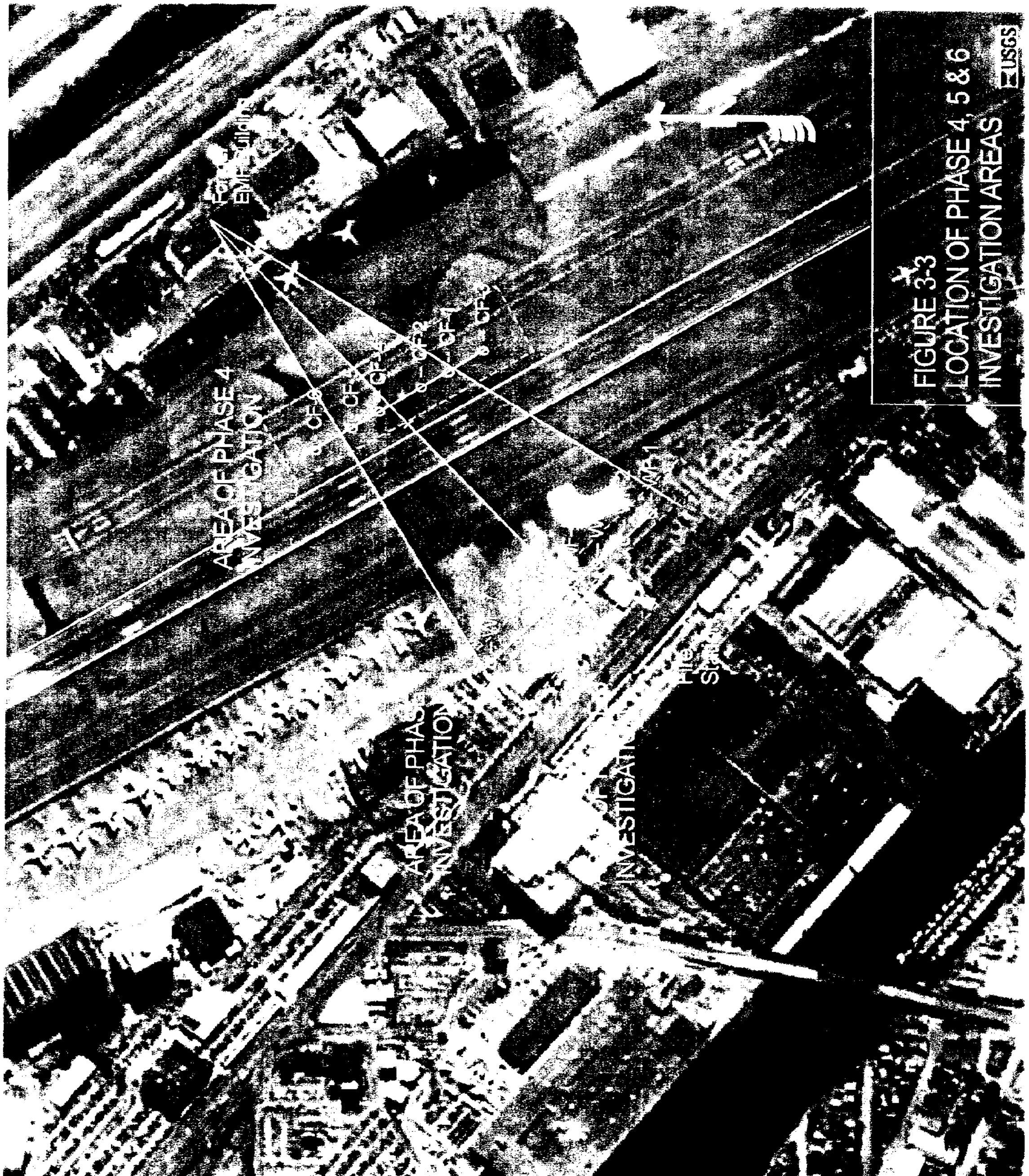


FIGURE 3-3
LOCATION OF PHASE 4, 5 & 6
INVESTIGATION AREAS

The Boeing EAL provided ~ 12 hour turn around for the first two nights of sampling and the results were evaluated prior to additional sampling. All of the sampling locations included multiple samples collected over depth and all sampling locations utilized field screening to identify the vertical interval where the highest VOC concentrations were present.

3.5 Phase 5 Sampling

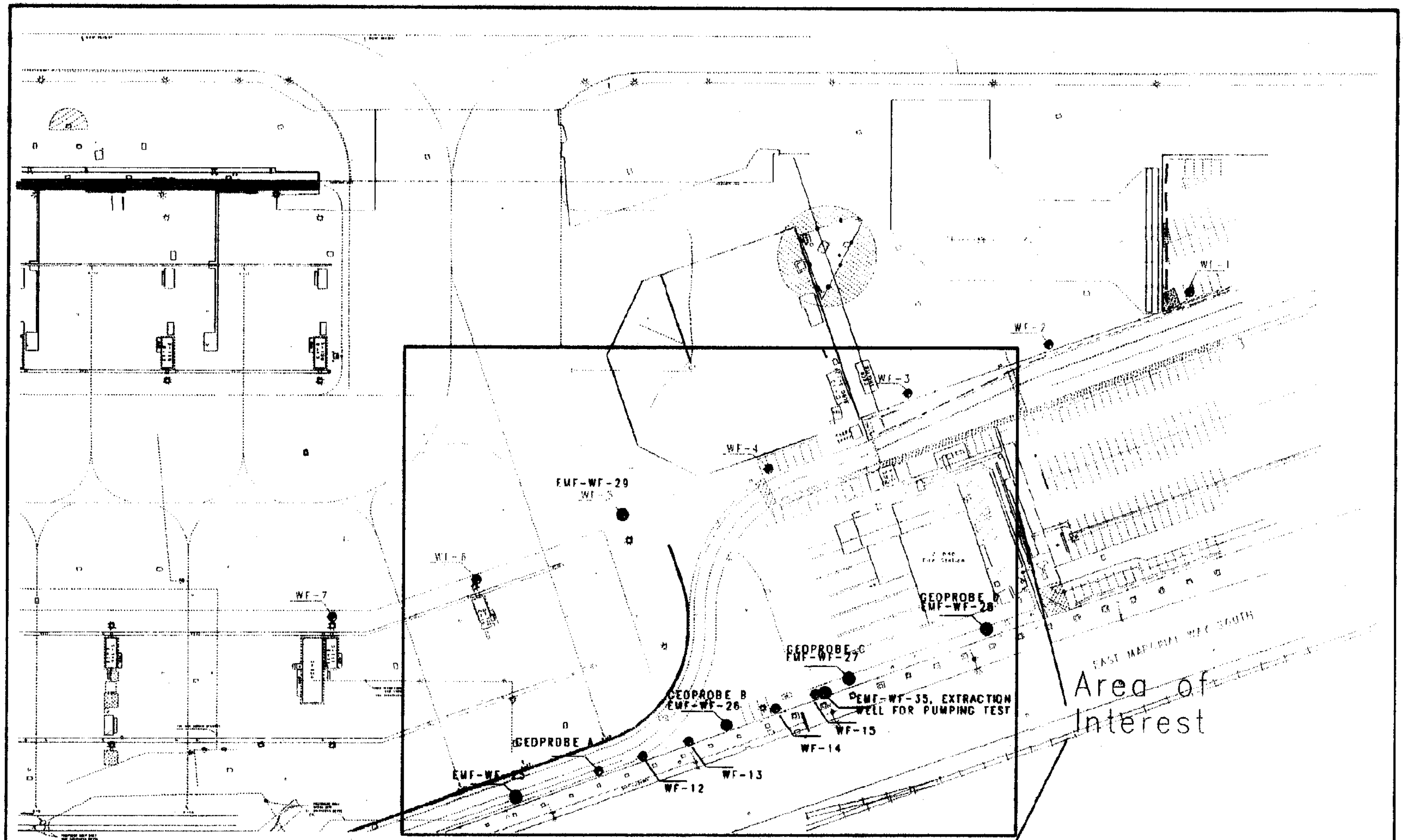
Phase 5 sampling activities involved collection of groundwater samples at locations along the western side of Boeing Field. These samples were collected to define the horizontal extent (i.e., width) of the plume in the area, as well as the vertical distribution of contaminants in the aquifer in this area. Samples were collected from seven locations, as previously shown in Figure 3-3. Sample locations were based on the expected location of the plume, as projected using the results of the Phase 4 sampling. As during Phase 4, samples were collected using a Geoprobe rig. Based on the results of the prior sampling, Phase 5 samples were collected over the same vertical interval as Phase 4 (i.e., from 30 ft bgs downward at 10 ft intervals). From two to four samples were collected at each location, depending on site stratigraphy.

Groundwater samples were submitted for laboratory analysis of VOCs using EPA Method 8260b. Samples for VOC analysis were collected in 40-mL glass septum-top vials with no headspace, acidified with hydrochloric acid, and preserved by cooling to 4°C or less. Samples were analyzed at Analytical Resources Inc. (ARI), a laboratory accredited by Ecology.

3.6 Phase 6 Sampling

Phase 6 field activities included installation of five new monitoring wells near the west side of Boeing Field. These wells were installed at the locations indicated in Figure 3-4. Four of the well locations are along the western boundary with west Marginal Way, where there had been no previous soil or groundwater sampling. As a result, Geoprobe borings were installed in this area to confirm the stratigraphy and collect groundwater samples. Geoprobe locations are identified as A, B, C, and D in Figure 3-4. Groundwater samples were analyzed for VOCs, as described above for Phases I and III. The final well locations were determined based on the results of analysis of these samples. In addition to these four wells, one additional well was installed upgradient along the approximate centerline of the plume. This upgradient well was installed to collect groundwater elevation data needed to determine the hydraulic gradient across the area. In addition to the water samples described above, samples of the aquifer material were also collected from the Geoprobes in order to determine particle-size distributions using American Society for Testing and Materials (ASTM) Method D422-63.

The wells were installed in boreholes drilled using 8-¼-inch outside diameter hollow-stem augers. Samples of aquifer materials were collected at approximately 5-ft intervals below the water table using a split spoon sampler. Monitoring wells were constructed inside the hollow-stem augers. Each well was installed with a 10-ft screened interval, with screen consisting of 2-in. diameter 0.010-in. factory-slotted polyvinyl chloride (PVC) screen. An end cap was installed on the bottom of each screen. The well casing above the screens consisted of 2-in. diameter schedule 40 PVC. The wells were completed below grade with the well heads located inside flush-mount surface monuments. A locking screw-plug well cap was installed in each well.



LEGEND
- Geoprobe Sampling Location
- Monitoring well location

APPROXIMATE SCALE IN FEET

Figure 3-4. Sampling Locations in EMF Plume, West Side of North Boeing Field

3.6.1 Aquifer Pumping Test

The aquifer pumping test was conducted based on the recommendations of the project peer review team to measure the hydraulic conductivity of the aquifer in the area of interest. The conductivity determined from the test is one of the key parameters used in transport and degradation rate constant calculations, as well as for design of any remedial actions deemed necessary. The aquifer pumping test was conducted in the specific stratigraphic interval of the aquifer where the EMF VOC plume is present. This vertical interval of the aquifer is expected to have a higher hydraulic conductivity (relatively) than other portions of the aquifer (based on visual observations of the soil texture and comparison of grain size distributions).

The test was conducted in three parts consisting of a step-drawdown test, a constant rate test, and a recovery test. The step-drawdown test was conducted by pumping the extraction well at increasing flow increments and measuring drawdown over time in the extraction well. The constant rate test was conducted by pumping the extraction well at a constant rate for a period of 24 hours. The water levels in five wells were monitored during the constant rate test. The recovery test began immediately after completion of the constant rate test. The recovery test was conducted by measuring recovery of the drawdown in the extraction well and observation wells over time after cessation of pumping.

Well EMF WF-35, a 4-inch diameter well, was used as the extraction well. Four 2-inch diameter wells were used as observation wells:

EMF WF-27	29 feet from EMF WF-35
EMF WF-26	92 feet from EMF WF-35
EMF WF-28	174 feet from EMF WF-35
EMF WF-29	259 feet from EMF WF-35

3.7 Quality Assurance

The quality assurance (QA) and quality control (QC) activities conducted during the RI indicated no concerns with respect to the usability of the RI data. Some of the samples required dilution in order to bring the sample concentration within the instrument calibration range. In these cases (i.e., where high VOC levels were present) some of the detection limits were elevated for other VOC compounds. This required dilution for analysis was only used in cases where VOCs were found to be at elevated levels. Therefore increased detection limits for other compounds are not of concern because they are within the plume where action levels are to be set by the VOCs that are present at high levels. Specific QA/QC activities are results are summarized below.

Samples were analyzed for VOCs using EPA method 8260b. The samples were labeled , sealed under chain of custody and delivered to the Boeing EAL or ARI on the day of collection. All samples were found to be intact on delivery to the EAL or ARI. The samples were preserved with hydrochloric acid, as specified in the project QA/field sampling plan (FSP). Analysis of all VOC samples was completed within the required 14-day holding time limit.

Laboratory QC has included surrogate spikes and analyses of method blanks, matrix spikes, matrix spike duplicates, and laboratory control samples (LCS). The surrogate recoveries and LCS results were all within the laboratory acceptance limits set by the lab. All VOCs were below method detection limits for all method blank samples. Results of analysis of matrix spikes and matrix spike duplicates were all within the laboratory acceptance limits for set by the lab.

Field QC activities included collection of field duplicate samples. The field duplicates taken during the different sampling events were all within the project QA/QC goals specified in the project QA/FSP.

4.0 Summary of Investigation Results

The section provides a brief summary of the new site characterization data collected and general interpretation of the results. The data are presented sequentially for the 6 phases of added field investigations that have been implemented.

4.1 Phase 1 Results and Interpretation

The first downgradient sampling was focused at the downgradient lease boundary of the EMF property. One existing well in the area (MW-5) indicated low levels of VOCs (at or near detection limits) but the well was completed at a shallow depth (~ 20 ft bgs). The subsequent sampling in this area during May 1999 included one-time Geoprobe samples and installation of monitoring wells (MW-11S, MW-11D and MW-13D). This lease property boundary is near front of where the UPS planes are parked in the area. The Geoprobe sampling included multiple samples collected over the depth of the aquifer from about 20 to 50 ft bgs.

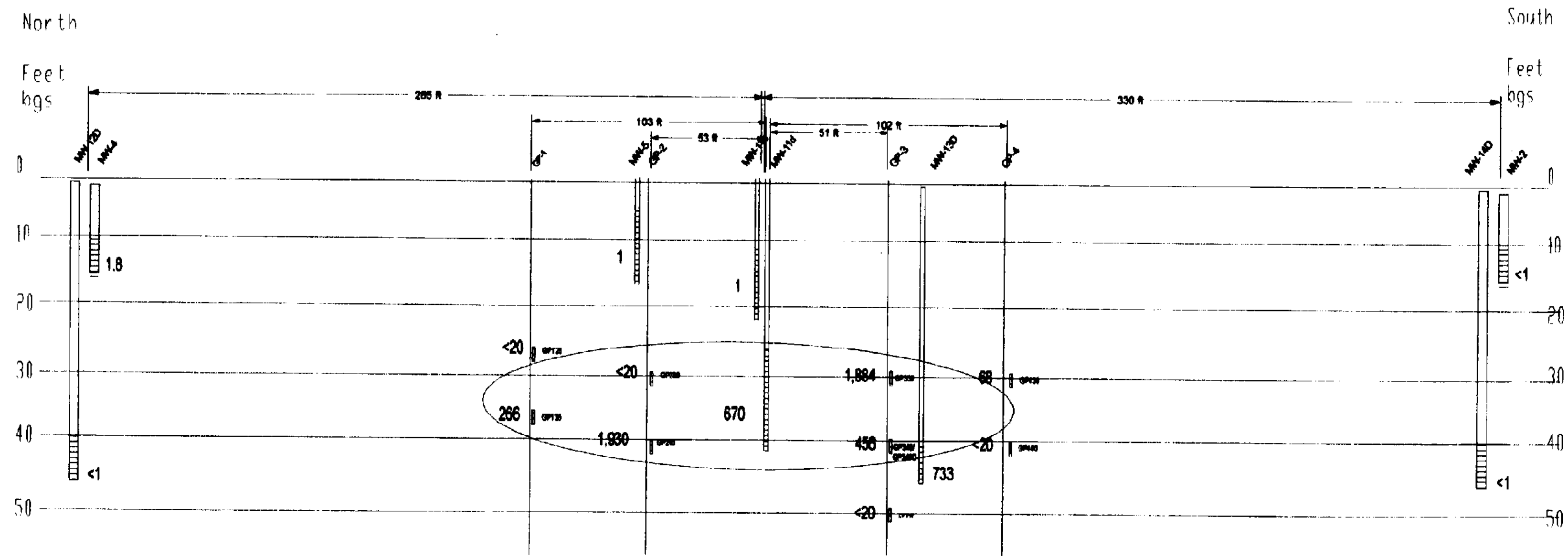
The results from the VOC sampling in this area are shown in Figures 4-1, 4-2, and 4-3 as vertical cross sections of the plume. Figure 3-1 presents the sampling locations in plan view. The results from this initial round of downgradient characterization and sampling indicated the following:

1) The VOC plume from the site was larger than anticipated in the initial RI/FS (1997) and the VOC plume extends beyond the lease property boundary.
2) The analytical results from the sampling indicated a thin, highly stratified VOC plume. The VOC plume was encountered at a depth of about 35 to 45 feet bgs and the VOC concentrations in this zone were in the range of 20,000 to 100,000 μg/L for the expected degradation byproducts. Monitoring wells in the shallow zone indicate low levels of VOCs in the range of 100 μg/L at a depth of 10 to 15 ft bgs.
3) These downgradient data indicate that the VOC plume was almost entirely converted from the initial TCE compound into the subsequent daughter products cis1,2-DCE and vinyl chloride.

The centerline of the plume migration pattern was mapped based on the results of Geoprobe sampling data collected after the EMF RI. As noted above, VOC sampling results indicated that TCE from the initial release area is being converted to the degradation products c1,2DCE and vinyl chloride. Data characterizing concentrations of TCE and degradation daughter products at various distances downgradient of the EMF source area, along with groundwater velocity were used to estimate first-order contaminant degradation rates. A first-order contaminant degradation model was developed and calibrated with the field data.

4.2 Phase 2 Results and Interpretation

The next phase of site investigation was focused at better delineation of the initial source area and peak concentrations in the on-site plume. This sampling was completed during February 2000 using a Geoprobe rig for collecting discrete groundwater and soil samples at numerous on-site locations and multiple depth intervals.

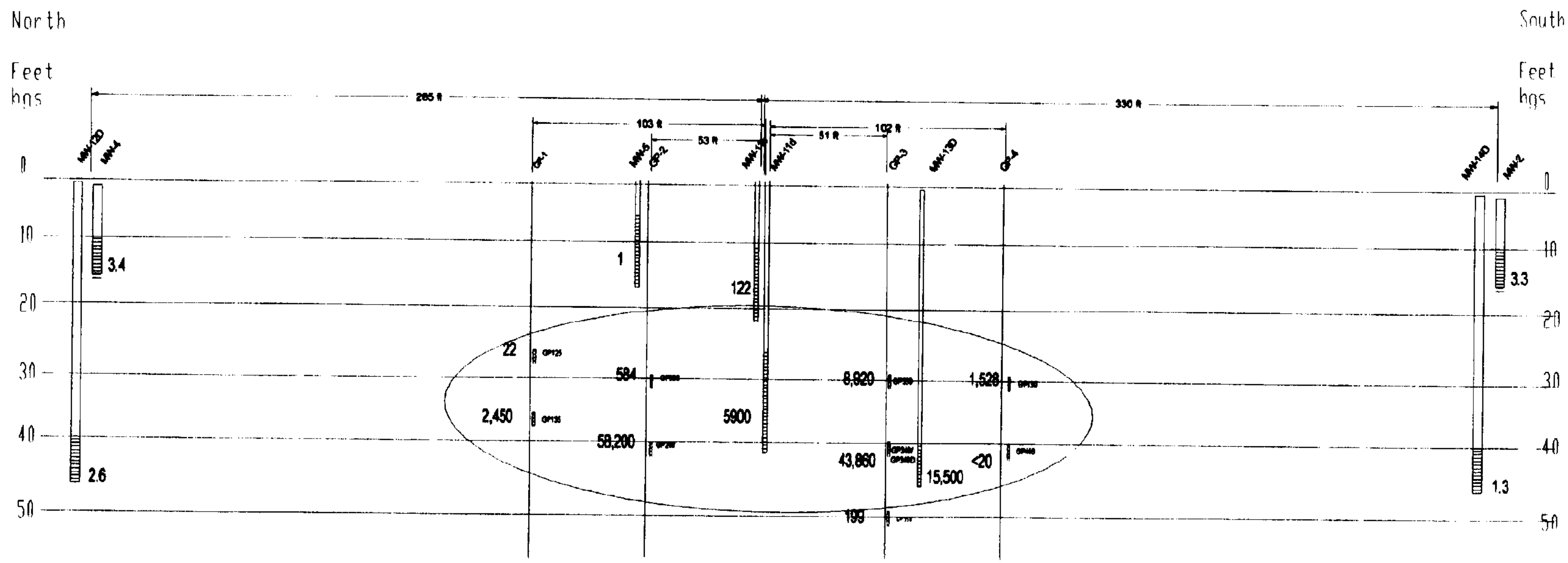


TCE concentration in ug/L , Cleanup goal is 2,000 ug/l

Geoprobe Sampling data collected on 5/19/99

Well sampling data collected on 7/28/99

PROJECT PERFORMANCE CORPORATION		
Figure 4-1. TCE Data, Transverse Cross Section of VOC Plume at Boundary, EMF Site		
SIZE NA	FSCM NO.	DWG NO. / FILE NAME EMF-X.SKD
SCALE as noted	DATE	SHEET 1 of 1

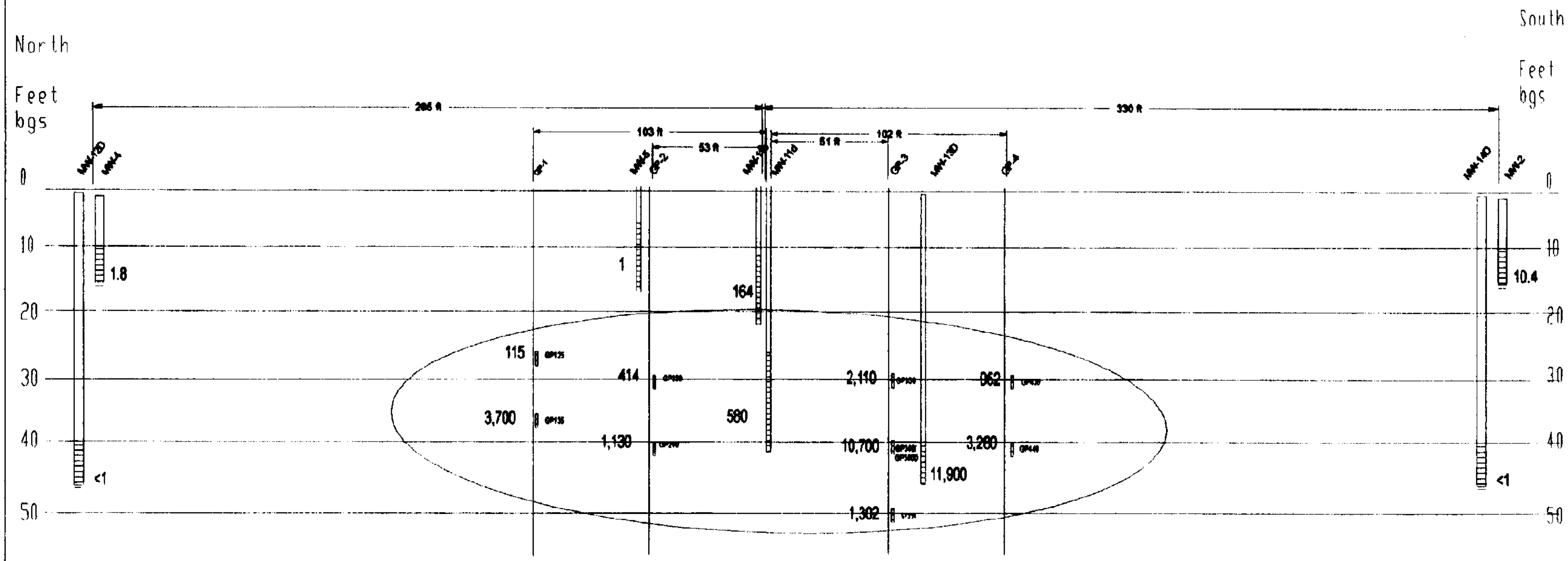


cis 1,2-DCE concentration in ug/L ,
Cleanup goal is 224,000 ug/l

Well sampling data collected on 7/28/99

Geoprobe Sampling data collected on 5/19/99

PROJECT PERFORMANCE CORPORATION		
Figure 4-2 cis-1,2 DCE Data, Transverse Cross Section of VOC Plume at EMF Boundary		
SIZE NA	FSCM NO.	DWG NO. / FILE NAME EMF-X.SKD
SCALE as noted	DATE	SHEET 1 of 1



Vinyl Chloride concentration in ug/L ,
Cleanup goal is 525 ug/l

Geoprobe Sampling data collected on 5/19/99

Well sampling data collected on 7/28/99

PROJECT PERFORMANCE CORPORATION			
Figure 4-3 Vinyl Chloride Data, Transverse Cross Section of VOC Plume at EMF Boundary			
SIZE NA	FSCM NO.	DWG NO. / FILE NAME EMF-X.SKD	
SCALE as noted	DATE	SHEET 1 of 1	

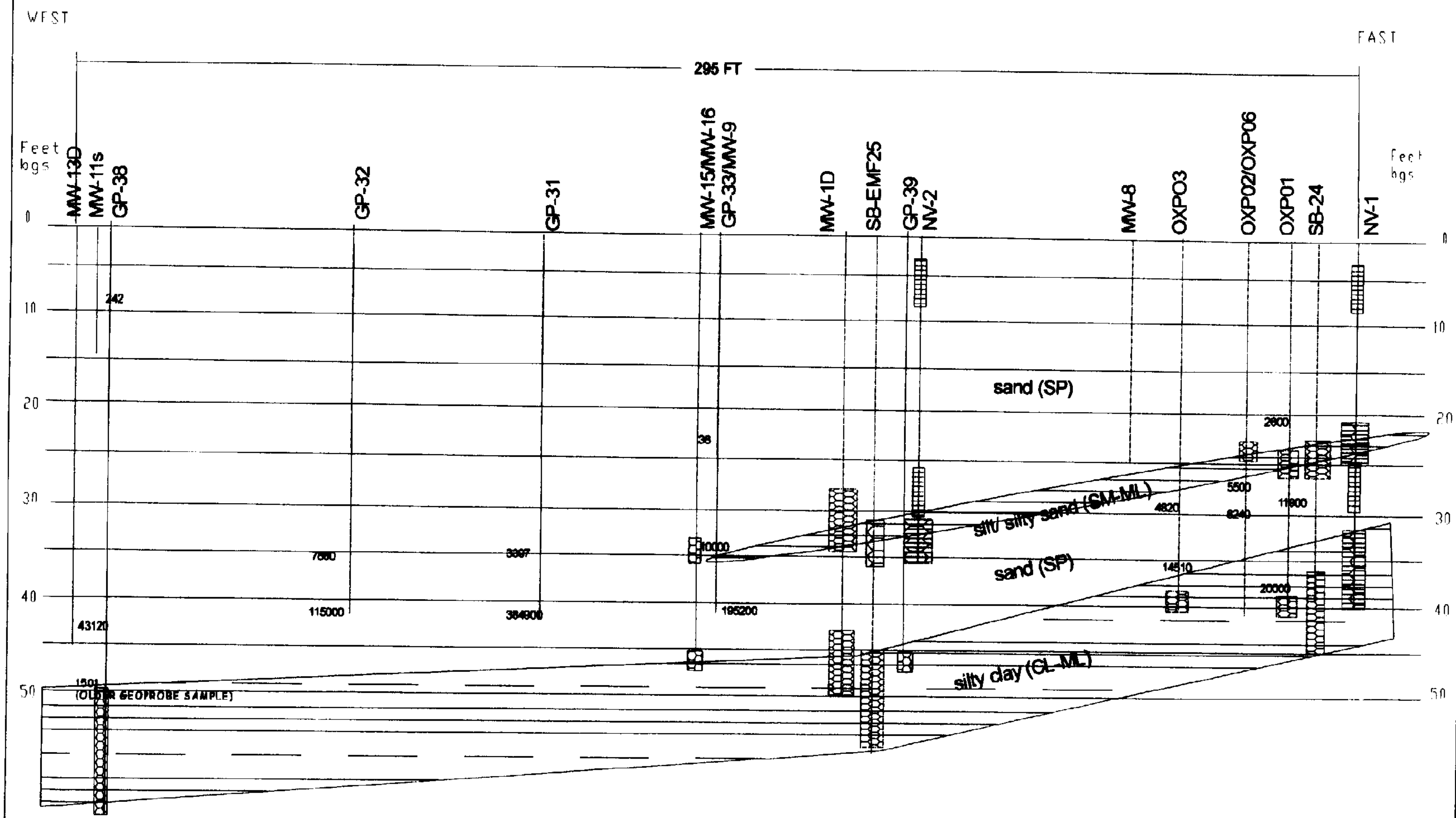
All sampling locations in this phase included field screening of multiple samples collected over depth and submitting water/soil samples for VOC analysis at the Boeing EAL. The field screening involved headspace analysis of a one-half full 40 ml VOA bottle using a photo ionizing detector (PID). Comparison of the analytical laboratory results with the field screening PID measurements demonstrated that the screening test was a reliable semi-quantitative measure of the presence of VOCs in groundwater at the site.

The first area investigated surrounded the location where separate phase TCE was recovered when the recirculating well treatment system was installed. This location was investigated in greater detail because TCE as a NAPL was confirmed present in the area (prior sampling and TCE recovery when the initial treatment system was started in 1997). At the time, preliminary plans were considering use of chemical oxidation in this area and detailed data were collected to map the three-dimensional location and extent of contamination. This sampling area surrounded existing treatment well NV-1. The location of sampling points (designated OXP1 through OXP10) are shown in Figure 3-2. Prior sampling locations from the EMF RI/FS (1997) are designated as GP14, GP27, etc. in Figure 3-2. The analytical results from this sampling are presented in Tables 4-1 and 4-2. Table 4-2 is a subset of Table 4-1 with only the data from locations closest to the point where TCE NAPL was recovered previously.

Additional sampling conducted at the same time included three Geoprobe sampling locations (designated GP-31, GP-32, GP-33) at positions between the downgradient treatment well (NV-2) and the lease property boundary where elevated VOC concentrations were detected in the prior Phase 1 sampling. The laboratory results from samples these samples are presented in Table 4-3.

The results from this phase of the site sampling and characterization indicated the following:

1) The initial area of the known TCE release (the location where TCE NAPL was recovered) no longer contains the highest concentrations.
2) In the immediate vicinity of the known TCE release location, the concentrations are reduced to levels that are no longer indicative of a continuing NAPL source in the area. Peak concentrations in groundwater are at concentrations less than 0.5% of the TCE solubility limit and extensive vertical and horizontal sampling has been conducted in the immediate area.
3) The highest VOC concentrations were detected downgradient of the existing treatment system area of influence. Peak concentrations of ~ 400,000 μg/L total VOCs were detected.
4) The site data indicate that the TCE is being rapidly degraded to the expected daughter products of cis1,2-DCE and vinyl chloride. At the source area TCE comprises almost 100% of the total VOCs, TCE in the downgradient samples is in the range of 0.1% to 0.5% of the total VOCs detected for the samples with high VOC levels.
5) The conceptual model of the site geology and plume distribution must be revised to reflect the observations of the thin stratified plume and the presence of a semi-confining layer at about 30 to 35 ft bgs. The revised conceptual model of site conditions is presented (as a cross section) in Figure 4-4.
6) The existing downgradient treatment well (NV-2) was completed in the upper aquifer zone and would not control the plume migration below the semi-confining layer present at 30 to 32 ft bgs. The majority of the VOCs are present in a permeable zone located about 35 to 45 ft bgs. Based on this interpretation, the existing NV-2 well was closed and replaced with a deeper well completed to a depth of 43 ft bgs. This well closure and replacement was completed in April 2000.



Geologic samples with fine grained silt or silty-clay units

43120 Total VOCs data from Jan/Feb 2000 ug/L

PROJECT PERFORMANCE CORPORATION		
Figure 4-4 Revised Geologic Cross Section (on-site and downgradient) EMF Site		
SIZE NA	FSCM NO.	DWG NO. / FILE NAME EMF-X.SKD
SCALE as noted	DATE	SHEET 1 of 1

KCSlip4 43941

SEA410471

Table 4-1 Results from Geoprobe Samples
Collected Near Known TCE Release Area, 2/12/2000

		VOC compounds μg/L			
location	**depth ft bgs**	**TCE**	**c12,DCE**	**t 12,DCE**	**vinyl chloride**
OXP01-22	19-23	1,160	1,444	0	13
-28	25-29	5,900	5,750	0	285
-33	31-35	1,340	263	13	0
-38	36-40	0	13,150	1,855	5,050
OXP02-22	20 -24	418	109	0	17
-27	25-29	2,645	2,690	0	165
-33	33-37	0	3,880	795	3,565
OXP03-29	27-31	135	4,580	0	105
-35	33-37	160	6,210	1,790	6,350
OXP04-24	22-26	3,955	275	0	100
-28	28-32	5,600	65	0	0
-36	34-38	29	33	3	0
OXP05-28	26-30	1,805	80	0	0
-33	31-35	824	100	0	0
-38	36-40	11	1,150	77	0
OXP06-26	26-30	1,543	112	0	0
-33	32-36	972	70	0	0
OXP07-22	20-24	12	28	6	30
-30	28-32	65	21	2	0
-36	34-38	3	35	6	0
OXP08-24	22-26	602	5	3	0
-32	30-34	3	0	0	0
OXP10-24	22-26	1,220	0	0	0
-32	30-34	4	0	0	0

Table 4-2 Data from Sampling Locations Closest to Known TCE Release Area, 2/12/2000

		Water concentration in $\mu g/L$			
location	**depth ft bgs**	**TCE**	**c12,DCE**	**t12DCE**	**v i n y l chloride**
OXP01-22	19-23	1,160	1,444	0	13
-28	25-29	5,900	5,750	0	285
-33	31-35	1,340	263	13	0
-38	36-40	0	13,150	1,855	5,050
OXP04-24	22-26	3,955	275	0	100
-28	28-32	5,600	65	0	0
-36	34-38	29	33	3	0
OXP07-22	20-24	12	28	6	30
-30	28-32	65	21	2	0
-36	34-38	3	35	6	0
		TCE	c12,DCE	t12DCE	vinyl chloride
	average	1,806	2,106	189	548
	max	5,900	13,150	1,855	5,050

Table 4-3 Results from Down Gradient Geoprobe Samples Collected on 2/12/2000

		VOC compounds $\mu g/L$			
location	**depth ft bgs**	**TCE**	**c12,DCE**	**t 12,DCE**	**vinyl chloride**
GP31	30-34	186	1,530	81	1,600
	36-40	500	281,000	16,800	86,600
GP32	30-34	925	6,000	535	2,540
	36-40	250	84,500	6,200	24,050
GP33	30-34	230	1,930	400	5,300
	36-40	1,000	78,800	25,600	89,800

4.3 Phase 3 Results and Interpretation

The next phase of site investigation was focused at better delineation of the distribution and boundaries of the on-site plume. This sampling was completed using a Geoprobe rig for collecting discrete groundwater and soil samples at numerous on-site locations and multiple depth intervals. All sampling locations in this phase included field screening of multiple samples collected over depth and submitting water/soil samples for VOC analysis at the Boeing EAL.

The sampling conducted in this phase was initiated to define the extent of the high concentrations present in the VOC plume (data needed for planning/design of source treatment remedial actions) and data to define the boundaries of the plume. The sampling locations were selected using an observational approach where a limited number of locations were sampled (between 6 and 9 in one day) and the results were evaluated prior to additional sampling. The Boeing EAL provided 1-day turn around for the key sampling events. All of the sampling locations included multiple samples collected over depth and all sampling locations utilized field screening to identify the vertical interval where the highest (if any) VOC concentrations were present.

A total of 27 new Geoprobe sampling locations were tested in this phase (designated GP-34 through GP-60) during March and April 2000. The locations were spread across the EMF site and downgradient areas . The western most locations were at the eastern taxiway (near the tail end of the parked UPS planes, designated GP-41 GP-42, GP43) and the southern most locations were near the southern plume boundary (locations designated GP-49, GP-50). The western most sampling locations (GP-41,GP-42,GP-43) are located on the on the west side of the former stream channel which cut through the area before the Duwamish Waterway was redirected to is present course.

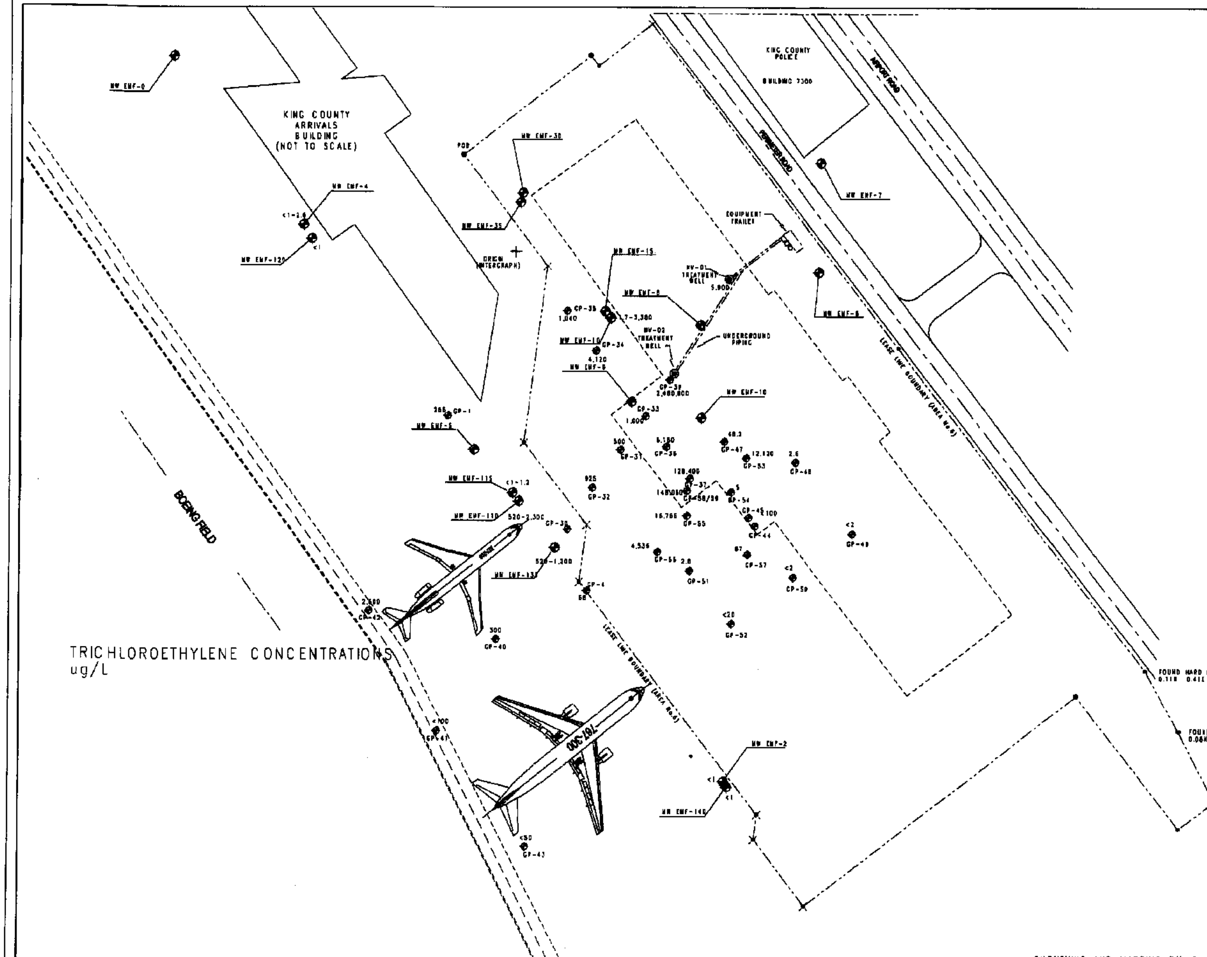
The analytical results from this phase of sampling are presented in Figures 4-5, 4-6 and 4-7. The analytical data presented in these figures are the peak concentrations detected over the vertical profile tested. The number of laboratory samples collected over depth varied from between two and four depending on the location. One sampling location in the central area of the plume (i.e., an area with the highest concentrations in the overlying aquifer), GP-38, was extended through the underlying aquitard found at ~ 45 to 55 ft bgs. Soil and water samples collected below the aquitard indicated non-detect levels for VOCs. This sampling location was closed by injecting grout under pressure in a tremie pipe from the bottom of the boring upward as the Geoprobe rod was removed.

The results from this phase of the site sampling and characterization indicated the following:

1) The vertical elevation of the VOC plume remains in a thin stratified plume present at about 35 to 45 ft bgs.

2) The western most sampling locations (GP-41 GP-42, GP43, at the eastern taxiway near the tail end of the parked UPS planes) indicate that the plume migration pattern appears to maintain the same direction after passing over the location of the former stream channel. The minimum plume width was estimated based on these sampling locations. VOC data from these locations indicated that the plume width in this area was at least 250 feet wide.

3) The southern most sampling locations (GP-49, GP-50) define the southern plume boundary with all VOCs near or below detection limits.



MONITOR WELL NO	STAMPED	ELEV. TOP WELL	ELEV TOP CASE	NORTHING	EASTING
EMF-8	NOT STAMPED	15.06	15.24	198,981	1,277,778
EMF-3D	NOT STAMPED	14.43	14.89	199,053	1,277,508
EMF-3S	NOT STAMPED	14.43	14.88	199,045	1,277,504
EMF-1S	NOT STAMPED	14.68	15.09	198,946	1,277,582
EMF-1D	NOT STAMPED	14.76	15.07	198,940	1,277,587
EMF-2	NOT STAMPED	13.46	13.89	198,515	1,277,682
EMF-5	NOT STAMPED	13.72	13.87	198,819	1,277,482
EMF-4	NOT STAMPED	13.93	14.24	199,024	1,277,304
EMF-7	NOT STAMPED	15.60	17.08	199,109	1,277,815
EMF-6	NOT STAMPED	14.53	14.85	198,933	1,277,670
EMF-9	NOT STAMPED	13.86	14.50	198,863	1,277,607
EMF-10	NOT STAMPED	14.44	14.72	198,848	1,277,671
EMF-11S	NOT STAMPED	13.58	13.96	198,779	1,277,487
EMF-11D	NOT STAMPED	13.51	13.97	198,772	1,277,503
EMF-12D	NOT STAMPED	13.67	14.10	198,811	1,277,311
EMF-13D	NOT STAMPED	13.71	14.10	198,728	1,277,536
EMF-14D	NOT STAMPED	13.43	13.81	198,522	1,277,688
HV-01	NOT STAMPED		14.83	198,978	1,277,696
HV-02	NOT STAMPED		14.81	198,860	1,277,646

ELEVATIONS WERE TAKEN ON THE NORTH RIM FOR BOTH TOP OF CASE AND TOP OF WELL

NOTES:
BUILDING FOOTPRINT SHOWN HEREON IS BASED FROM THE LOCATION OF THE EXISTING E.M.F. FOUNDATION AS MAPPED BY DHA ASSOCIATES, INC. IN MAY 1996. FOUNDATION MAPPING OCCURRED AFTER THE DEMOLITION OF THE E.M.F. BUILDING.

ORIGIN (INTERGRAPH)
X 1,277,500
Y 199,000

LEASE AREA No.6
LEASE LINE SHOWN HEREON IS APPROXIMATE ONLY

SURVEYING AND MAPPING BY: DUANE HARTMAN AND ASSOCIATES, INC.

SYM	REVISION	BY	APPROVED	DATE
	ADDED APPROXIMATE LEASE LINE BOUNDARY	DAH		03/12/97
	ADDED WELLS EMF-8 THROUGH EMF-11D	CHB		02/02/99
	ADDED WELLS 12 THROUGH 14	CHB		05/26/99
	PROPERTY CORNER STAKEOUT & WELL TIES	GRB		08/02/99

BOEING

ACCEPTABILITY
THE DESIGN AND/OR SPECIFICATION IS APPROVED
APPROVED BY | DEPT. | DATE

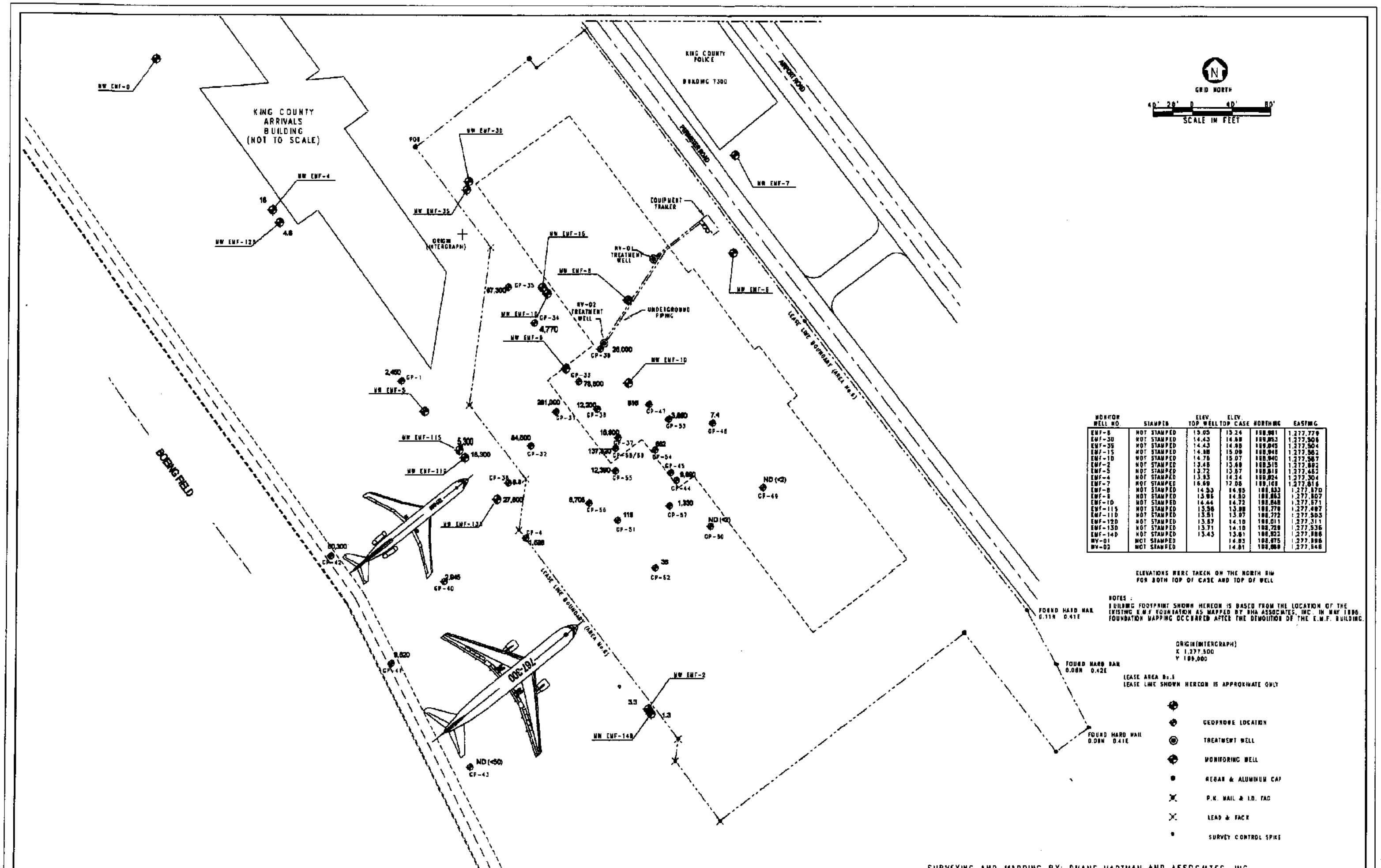
DRAWN BY | DATE
CHECKED
ENGR.
CHECKED
APPROVED
APPROVED

FIGURE 4-5 PHASE 3 GROUNDWATER SAMPLING RESULTS, TCE IN GROUNDWATER (ug/L)

DHA JOB No.639.00

KCSlip4 43945

SEA410475



MONITOR WELL NO.	STAMPED	ELEV. TOP WELL	ELEV. TOP CASE	NORTHING	EASTING
EMF-6	NOT STAMPED	13.05	13.24	[illegible]	1,277,779
EMF-30	NOT STAMPED	14.43	14.68	[illegible]	1,277,506
EMF-35	NOT STAMPED	14.43	14.98	189,045	1,277,504
EMF-15	NOT STAMPED	14.88	15.09	[illegible]	1,277,582
EMF-10	NOT STAMPED	14.76	15.07	188,940	1,277,587
EMF-2	NOT STAMPED	13.46	13.60	188,515	[illegible]
EMF-5	NOT STAMPED	13.72	13.87	[illegible]	1,277,462
EMF-4	NOT STAMPED	13.93	14.34	188,824	1,277,304
EMF-7	NOT STAMPED	16.69	17.08	189,108	1,277,816
EMF-8	NOT STAMPED	14.53	14.95	[illegible]	1,277,870
EMF-9	NOT STAMPED	13.96	14.50	[illegible]	1,277,807
EMF-10	NOT STAMPED	14.44	14.72	188,848	1,277,671
EMF-115	NOT STAMPED	13.58	13.88	188,770	1,277,407
EMF-110	NOT STAMPED	13.51	13.97	188,772	1,277,503
EMF-120	NOT STAMPED	13.67	14.10	188,011	1,277,311
EMF-130	NOT STAMPED	13.71	14.10	188,729	1,277,536
EMF-140	NOT STAMPED	13.43	13.61	188,523	[illegible]
RV-01	NOT STAMPED		14.83	188,975	[illegible]
RV-02	NOT STAMPED		14.81	[illegible]	1,277,648

ELEVATIONS WERE TAKEN ON THE NORTH RIM FOR BOTH TOP OF CASE AND TOP OF WELL

NOTES :
BUILDING FOOTPRINT SHOWN HEREON IS BASED FROM THE LOCATION OF THE EXISTING E.M.F. FOUNDATION AS MAPPED BY DHA ASSOCIATES, INC. IN MAY 1996. FOUNDATION MAPPING OCCURRED AFTER THE DEMOLITION OF THE E.M.F. BUILDING.

ORIGIN(INTERGRAPH)
X 1,277,300
Y 189,000

LEASE AREA No.6
LEASE LINE SHOWN HEREON IS APPROXIMATE ONLY

SURVEYING AND MAPPING BY: DUANE HARTMAN AND ASSOCIATES, INC.

REVISION	BY	APPROVED	DATE
ADDED APPROXIMATE LEASE LINE BOUNDARY	DAH		03/12/97
ADDED WELLS EMF-8 THROUGH EMF-11D	CMB		03/03/9[illegible]
ADDED WELLS 12 THROUGH 14	CMB		05/28/9[illegible]
PROPERTY CORNER STAKEOUT & WELL TIES	CRB		09/02/9[illegible]

ACCEPTABILITY
THIS DESIGN AND/OR SPECIFICATION IS APPROVED

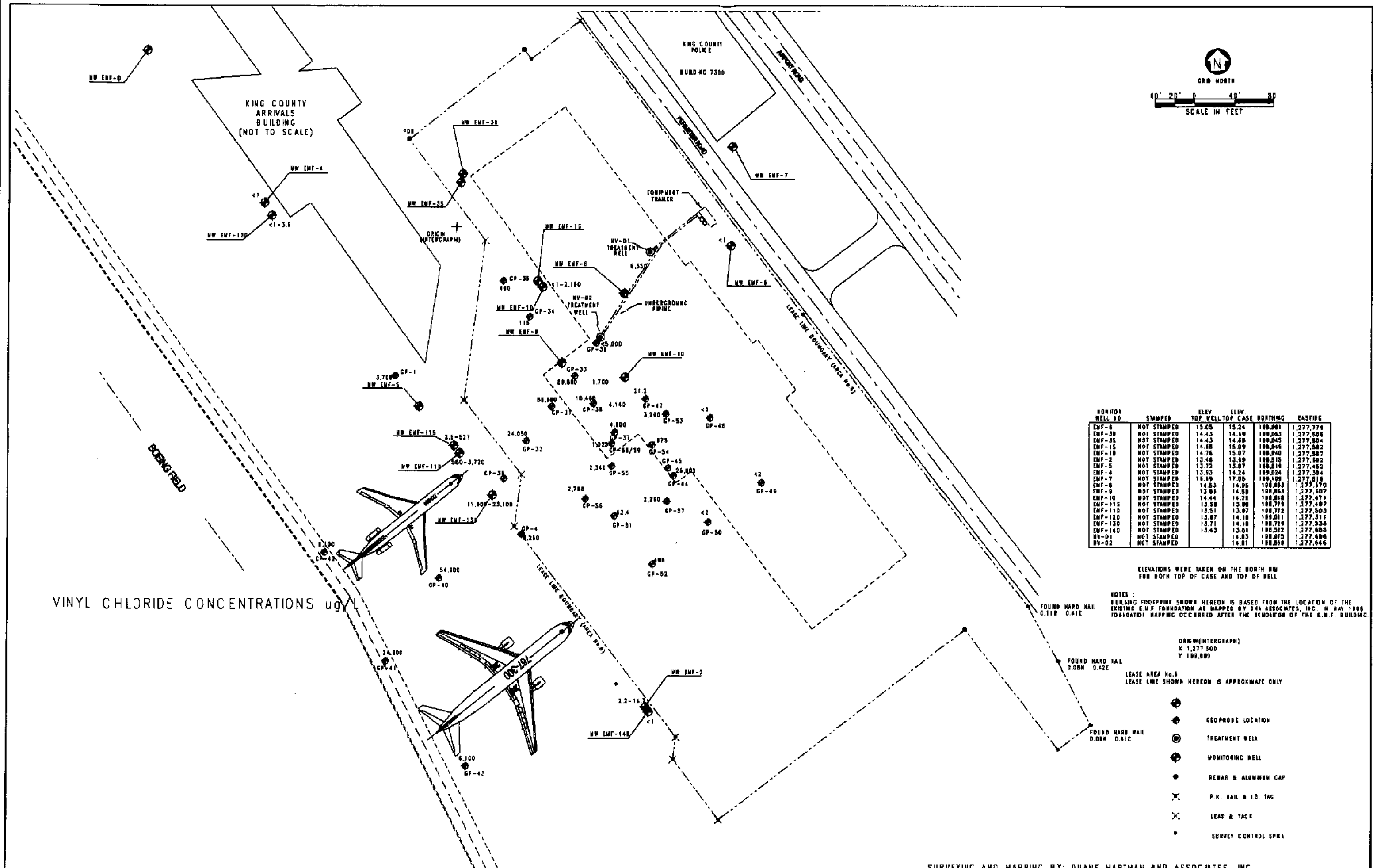
APPROVED BY	DEPT.	DATE

FIGURE 4-6 PHASE 3 GROUNDWATER SAMPLING RESULTS, cis-1,2 DCE IN GROUNDWATER (ug/L)

DHA JOB No.839.90

KCSIip4 43946

SEA410476



MONITOR WELL NO	STAMPED	ELEV. TOP WELL	ELEV. TOP CASE	NORTHING	EASTING
EMF-6	NOT STAMPED	15.05	15.24	198,981	1,277,779
EMF-3D	NOT STAMPED	14.43	14.59	199,063	1,277,506
EMF-3S	NOT STAMPED	14.43	14.68	199,045	1,277,504
EMF-1S	NOT STAMPED	14.88	15.09	198,946	1,277,582
EMF-1D	NOT STAMPED	14.76	15.07	198,940	1,277,587
EMF-2	NOT STAMPED	13.46	13.69	198,515	1,277,692
EMF-5	NOT STAMPED	13.72	13.87	198,619	1,277,452
EMF-4	NOT STAMPED	13.93	14.24	199,024	1,277,304
EMF-7	NOT STAMPED	16.69	17.08	199,109	1,277,818
EMF-8	NOT STAMPED	14.53	14.85	198,833	1,277,670
EMF-9	NOT STAMPED	13.85	14.50	198,863	1,277,607
EMF-10	NOT STAMPED	14.44	14.72	198,848	1,277,671
EMF-11S	NOT STAMPED	13.58	15.88	198,779	1,277,407
EMF-11D	NOT STAMPED	13.51	13.87	198,772	1,277,503
EMF-12D	NOT STAMPED	13.87	14.10	199,011	1,277,311
EMF-13D	NOT STAMPED	13.71	14.10	198,729	1,277,338
EMF-14D	NOT STAMPED	13.43	13.81	198,522	1,277,688
NV-01	NOT STAMPED		14.83	198,875	1,277,606
NV-02	NOT STAMPED		14.81	198,850	1,277,646

ELEVATIONS WERE TAKEN ON THE NORTH RIM FOR BOTH TOP OF CASE AND TOP OF WELL

NOTES :
BUILDING FOOTPRINT SHOWN HEREON IS BASED FROM THE LOCATION OF THE EXISTING E.M.F FOUNDATION AS MAPPED BY DHA ASSOCIATES, INC. IN MAY 1998 FOUNDATION MAPPING OCCURRED AFTER THE DEMOLITION OF THE E.M.F. BUILDING.

ORIGIN (INTERGRAPH)
X 1,277,500
Y 199,000

LEASE AREA No.6
LEASE LINE SHOWN HEREON IS APPROXIMATE ONLY

GEOPROBE LOCATION
TREATMENT WELL
MONITORING WELL
REBAR & ALUMINUM CAP
P.K. NAIL & I.D. TAG
LEAD & TACK
SURVEY CONTROL SPIKE

SURVEYING AND MAPPING BY: DUANE HARTMAN AND ASSOCIATES, INC.

SYM	REVISION	BY	APPROVED	DATE
	ADDED APPROXIMATE LEASE LINE BOUNDARY	DAH		03/12/9?
	ADDED WELLS EMF-8 THROUGH EMF-11D	CHB		02/02/9?
	ADDED WELLS 12 THROUGH 14	CHB		05/20/9?
	PROPERTY CORNER STAKEOUT & WELL TIES	CRB		09/02/9?

BOEING

ACCEPTABILITY
THIS DESIGN AND/OR SPECIFICATION IS APPROVED
APPROVED BY | DEPT. | DATE

DRAWN BY | DATE
CHECKED
ENGR.
CHECKED
APPROVED
APPROVED

FIGURE 4-7 PHASE 3 GROUNDWATER SAMPLING RESULTS, Vinyl Chloride IN GROUNDWATER (ug/L)

DHA JOB No.639.00

KCSlip4 43947

SEA410477

4) Soil and water samples collected from the deeper aquifer zone (GP-38) indicate that the VOC plume has not migrated through the underlying aquitard. This is consistent with prior samples collected in the 1997 EMF RI. This sampling location is located in the central area of the plume with peak VOC concentrations present in the overlying aquifer.

4.4 Phase 4 Results and Interpretation

Based on the revised conceptual model of the VOC plume, the next phase of sampling was planned on the western side of Boeing Field. Following review of the investigation work plan by King County, the plan was modified to include sampling in the middle of Boeing Field (between the runways). This phase of sampling involved collecting groundwater samples from Geoprobe borings installed in the grassy strip between the two active runways, approximately 1,000 ft downgradient of the EMF source area.

The samples were collected during November 2000 from six locations across the projected location of the plume. The boring locations in this area were designated CF-1, through CF-6 (the CF designation stands for Center of Field), sample locations are shown in Figure 3-3. The sampling and analysis results are presented in Table 4-4 and Figure 4-8. The analytical results from the samples indicated VOCs in excess of AWQCs from boring CF-1 northward to boring CF-5, a distance of approximately 400 ft. Boring CF-1 was placed at the estimated location of the centerline of the plume, as based on results of previous groundwater sampling and the groundwater gradient at the EMF site. Based on the results shown in Table 4-4 and Figure 4-8, the actual centerline of the plume actually appears to be in the vicinity of boring CF-2, approximately 150 ft northwest of the initial estimate. This revised centerline location is consistent with the regional groundwater gradient, as it is approximately perpendicular to the Duwamish Waterway (see Section 2.4.2).

As shown in Figure 4-8, concentrations of VOCs above AWQCs were generally limited to the depth interval 40 to 44 ft bgs, but were also detected in the interval 47 to 51 ft bgs in one location (Boring CF-4). The concentrations of vinyl chloride detected in the samples from 40 to 44 ft bgs were generally one order of magnitude or more higher than the concentrations in the samples from 30 ft bgs. Similarly, in Borings CF-1, CF-2, and CF-5, the vinyl chloride concentrations in samples from 40 to 44 ft bgs were also one or more orders of magnitude higher than the concentrations in samples from 47 to 51 ft bgs. These results are indicative of a stratified plume, which is consistent with previous upgradient sampling results from the EMF site. The results of the chloride analyses showed no clear relationship between chloride concentrations and VOC concentrations.

The results from this phase of the site sampling and characterization indicated the following:

1) The vertical elevation of the VOC plume remains in a thin stratified plume present at about 40 to 50 ft bgs.

2) VOC data from these locations indicate that the plume width in this area was approximately 500 feet wide (at levels above the AWQCs).

3) Peak concentrations of cis1,2-DCE were detected at 30,000 μgl/L and vinyl chloride at 8,600 μg/L. The locations where the peak concentrations were detected are not co-located. TCE was also detected at one location at a level of 11,000 μg/L (~25% of the total VOCs present) , this detection was somewhat surprising because it indicated that in this specific location the TCE was not fully degraded to the expected daughter products (as upgradient sampling locations had indicated).

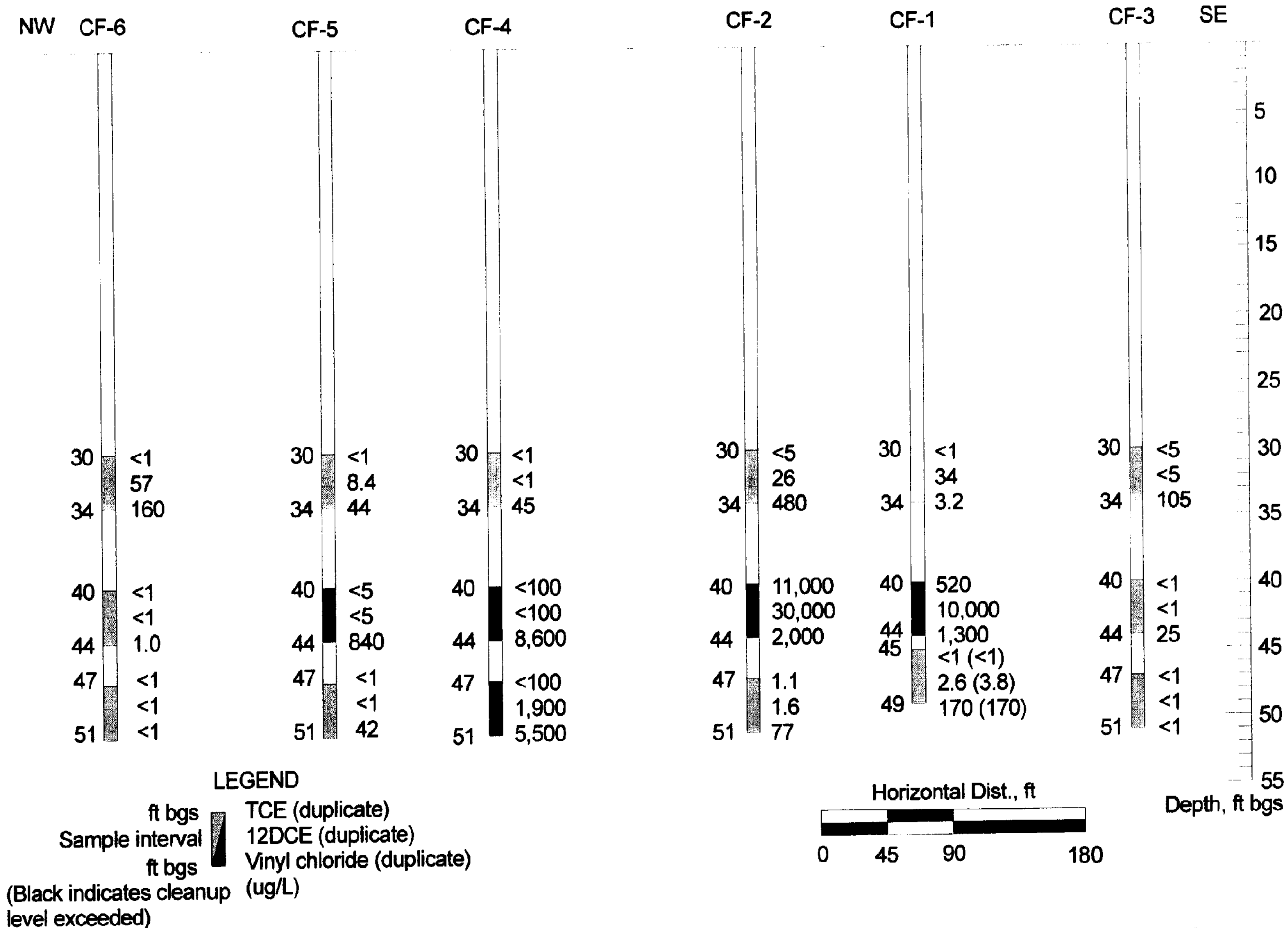


Figure 4-8. Results of Phase 4 Geoprobe Sampling in Center of Boeing Field

Table 4-4. Summary of Analytical Results From Phase 4 Sampling.

Location Name	Description	Sampling depth interval, ft bgs	TCE µg/L	c1,2DCE µg/L	Vinyl chloride µg/L	Chloride mg/L
CF-3 southern-most location	150 ft SE of estimated centerline	30 -- 34	<5.0	<5.0	105	25
		40 – 44	<1.0	<1.0	25	320
		47 – 51	<1.0	<1.0	<1.0	2000
CF-1	initial estimate of centerline	30 – 34	<1.0	34	3.2	3.0
		40 – 44	520	10,000	**1,300**	35
		45 – 49	<1.0	2.6	170	730
		45 – 49 duplicate	<1.0	3.8	170	700
CF-2	150 ft NW of estimated centerline	30 – 34	<5.0	26	480	12
		40 – 44	**11,000**	30,000	**2,000**	68
		47 – 51	1.1	1.6	77	1,300
CF-4	350 ft NW of estimated centerline	30 – 34	<1.0	<1.0	45	14
		40 – 44	<100	<100	**8,600**	32
		47 – 51	<100	1,900	**5,500**	NS
CF-5	500 ft NW of estimated centerline	30 – 34	<1.0	8.4	44	13
		40 – 44	<5.0	<5.0	**840**	100
		47 – 51	<1.0	<1.0	42	700
CF-6 northern most location	650 ft NW of estimated centerline	30 – 34	<1.0	57	160	13
		40 – 44	<1.0	<1.0	1.0	200
		47 – 51	<1.0	<1.0	<1.0	780

Shaded cells contain values exceeding cleanup standards. The standards set for protection of aquatic resources and beneficial use of groundwater discharging to the Duwamish Waterway are 2,000 µg/L TCE; 220,000 µg/L c1,2DCE; and 525 µg/L vinyl chloride.

4.5 Phase 5 Results and Interpretation

The next phase of sampling was collecting groundwater samples from Geoprobe borings installed on the west side of the active runways and taxiways, approximately 1,800 ft downgradient of the EMF source area. This sampling was completed in February 2001. Samples were collected from seven locations across the projected location of the plume and were collected at several depths, based on the vertical distribution of contaminants at upgradient sample locations. Sample locations are shown in Figure 3-3 and sampling and analysis results are presented in Table 4-5 and Figure 4-9.

The results indicate VOCs in excess of AWQCs in samples from Borings WF-4 and WF-5, which were placed near the estimated location of the plume centerline, as determined from the results of the prior sampling and regional groundwater gradient. These boring locations are downgradient of Boring CF-4, and appear to confirm the migration of the centerline of the VOC plume.

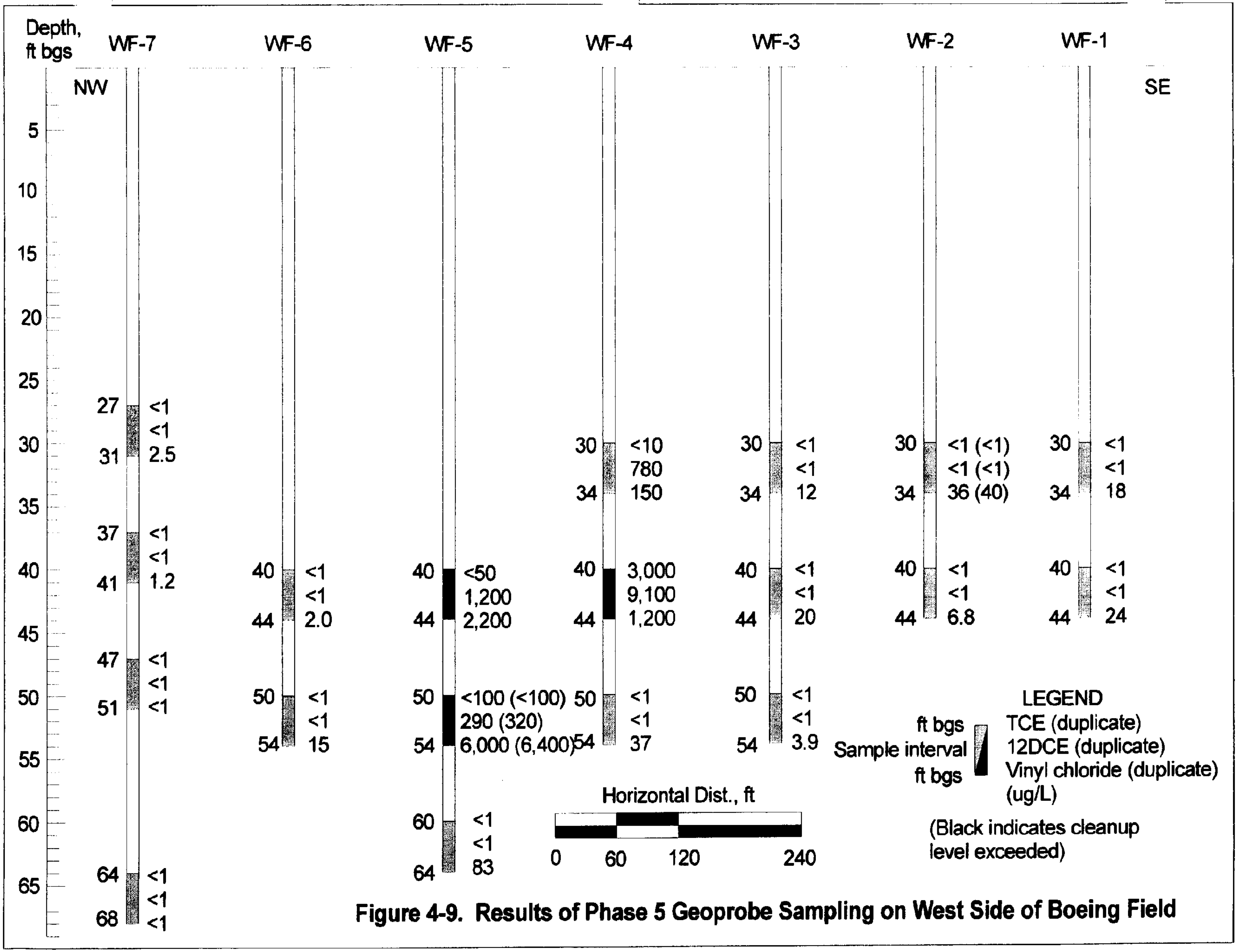


Figure 4-9. Results of Phase 5 Geoprobe Sampling on West Side of Boeing Field

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The vertical distribution of VOCs was similar to that from prior investigations, with concentrations above AWQCs being detected in samples from 40 to 44 ft bgs (WF-4 and WF-5) and 50 to 54 ft bgs (WF-5 only). Again, the results are consistent with the presence of a stratified plume with the highest concentrations in samples collected between 40 and 50 feet bgs.

Table 4-5. Summary of Analytical Results From Phase 5 Sampling.

Location Name & Description	Sampling depth interval, ft bgs	TCE μg/L	c1,2DCE μg/L	Vinyl chloride μg/L
WF-1 Southern most location, South of blast fence	30 – 34	<1.0	<1.0	18
	40 – 44	<1.0	<1.0	24
WF-2 Along fence after storage lockers	30 — 34	<1.0	<1.0	36
	30 - 34 duplicate	<1.0	<1.0	40
	40 – 44	<1.0	<1.0	6.85
WF-3 Along fence in security parking area	30 – 34	<1.0	<1.0	12
	40 – 44	<1.0	<1.0	20
	50 – 54	<1.0	<1.0	3.9
WF-4 Near estimated centerline of VOC plume	30 – 34	<10	780	150
	40 – 44	**3,000**	9,100	**1,200**
	50 – 54	<1.0	<1.0	37
WF-5 Near estimated centerline of VOC plume, (1st light stand in delivery area)	40 – 44	<50	1,200	**2.200**
	50 – 54	<100	290	**6,000**
	50 – 54 duplicate	<100	320	**6,400**
	60 – 64	<1.0	<1.0	83
WF-6 (2nd light stand in delivery area)	40 – 44	<1.0	<1.0	2.0
	50 – 54	<1.0	<1.0	15
WF-7, northern most location, (3rd light stand in delivery area)	27 – 31	<1.0	<1.0	2.5
	37 – 41	<1.0	<1.0	1.2
	47 – 51	<1.0	<1.0	<1.0
	64 – 68	<1.0	<1.0	<1.0

Shaded cells contain values exceeding cleanup standards. The standards set for protection of aquatic resources and beneficial use of groundwater discharging to the Duwamish Waterway are 2,000 μg/L TCE; 220,000 μg/L c1,2DCE; and 525 μg/L vinyl chloride.

The concentrations of VOCs in the Phase 5 samples are lower than the concentrations in corresponding upgradient Phase 4 samples. The previously-developed degradation model was used to predict maximum VOC concentrations along the plume centerline and VOC concentrations along the plume cross-sections sampled during Phases 4 and 5. These results are shown in Figures 4-10, and 4-11 respectively. These model-predicted concentrations are based on a total VOC half life of 19 months and show good agreement with measured concentrations. These model results indicate that the VOC plume should continue to undergo significant concentration reduction due to natural degradation between the western side of Boeing Field and the Duwamish Waterway.

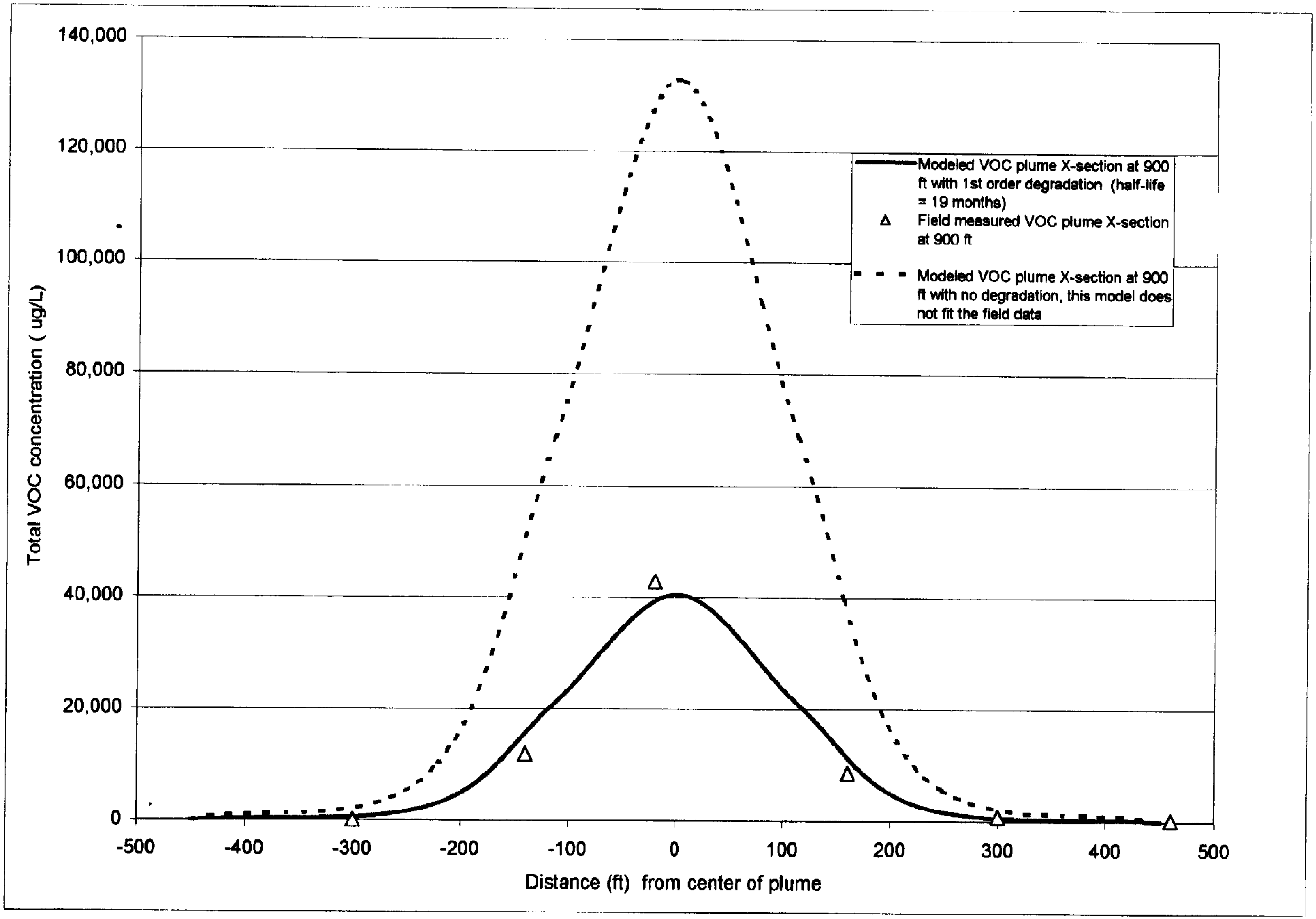

Figure 4-10 Measured and Modeled VOC Plume Cross section at 900 ft From Source

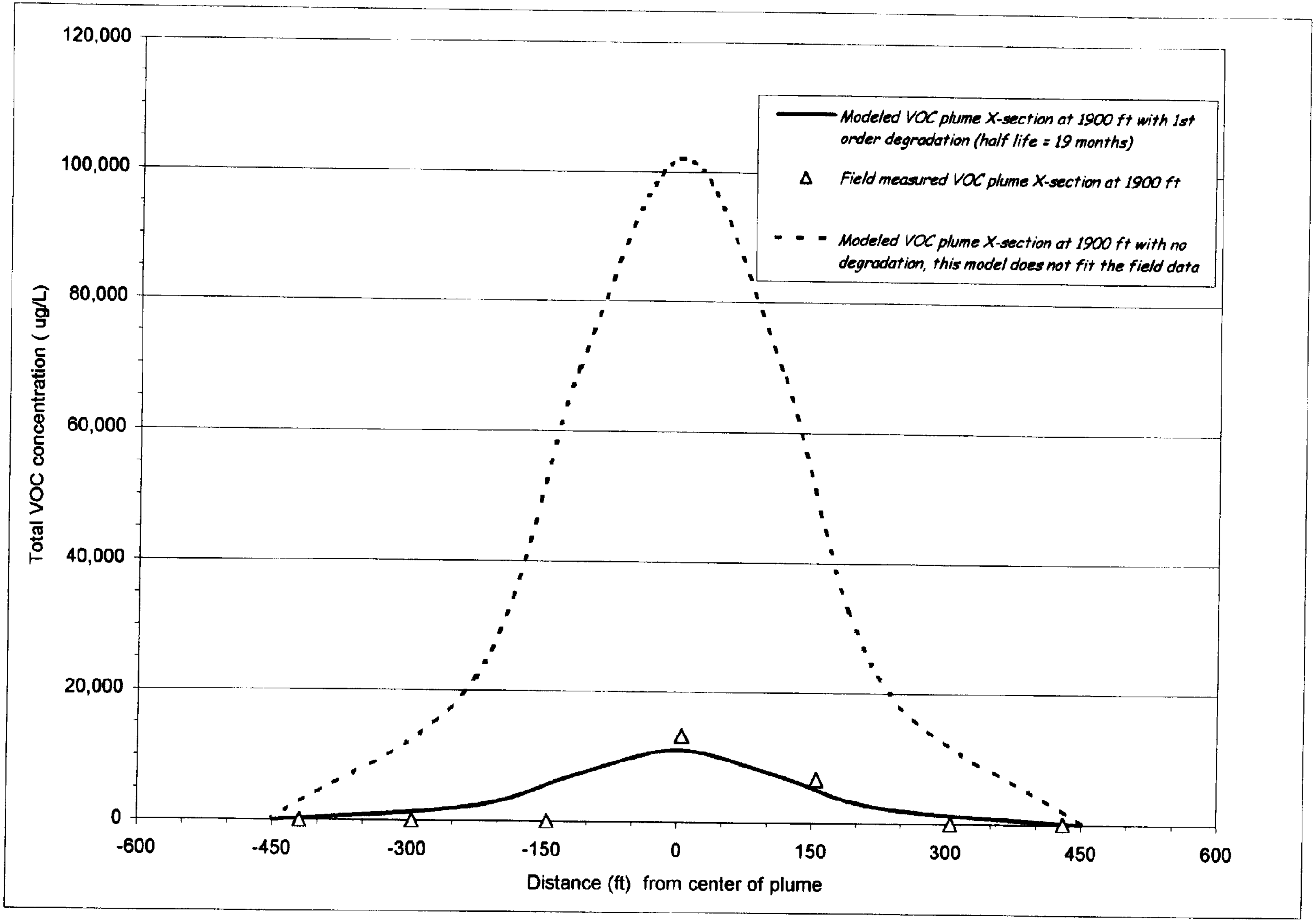

Figure 4-11 Measured and Modeled VOC Plume Cross Section at 1900 ft From Source

The results from this phase of the site sampling and characterization indicated the following:

1) The vertical elevation of the VOC plume remains in a thin stratified plume present at about 40 to 55 ft bgs.

2) VOC data from these locations indicate that the plume width in this area was approximately 300 feet wide (at levels above the AWQCs).

3) Peak concentrations of cis1,2DCE were detected at 9,100 μg/L and vinyl chloride at 6,400 μg/L. The locations where the peak concentrations were detected are not co-located. TCE was also detected at one location at a level of 3,000 μg/L (~22% of the total VOCs present).

4.6 Phase 6 Results and Interpretation

The Phase 6 activities included installation and sampling of new monitoring wells (6 wells) in April 2001 at/near the western side of Boeing Field , geologic characterization, collecting soil samples for grain size analysis, and conducting an aquifer pumping test. Five of the new wells were located along the western (i.e., downgradient) boundary of the airfield along West Marginal Way. The sixth well was located upgradient of these, at the WF-5 sampling location from Phase 5, in order to provide groundwater elevation data with which to determine the gradient across the area. Prior to installing the wells along the western boundary, four Geoprobe borings were installed at preliminary well locations. These Geoprobe locations are identified as A, B, C, and D in Figure 4-12. Groundwater samples were collected at selected depths from these borings. The final well locations were selected based on results from laboratory analysis of these samples. Wells EMF-WF-26, EMF-WF-27, and EMF-WF-28 were located at Geoprobes B, C, and D, respectively. Well EMF-WF-25 was located to the northwest of Geoprobe A. Well EMF-WF-29 was located to the east (to provide water level data for calculating the gradient in the area). Well EMF-WF-35 was later installed 29 feet north of well EMF-WF-27 as a four inch well to be used as an extraction well during the pumping test.

Based on review of analytical data from these locations, the project peer review team suggested that higher data density may be appropriate in this area of the plume in order to identify peak VOC concentrations that could be present (the existing sampling locations were spaced on 125 ft centers). In order to satisfy this additional data need, four more Geoprobe locations were sampled in the central area of the plume to provide a higher density of samples (~ 40 ft centers) within the area of the plume with the highest VOC concentrations. Well locations are also shown in Figure 4-12.

Groundwater samples were collected during August 2001at various depths from the seven Geoprobe borings and were analyzed for VOCs. These results, along with three of the wells, are presented in Table 4-6 and Figure 4-13. These results are consistent with the previous sampling in terms of the vertical and horizontal distribution of VOC contamination. Based on the results of this sampling, the VOC plume (i.e., concentrations above AWQCs) is expected to be approximately 300 ft wide at the western boundary of Boeing Field.

Monitoring wells were then installed and sampled. Groundwater samples were analyzed for VOCs, as well as general water quality parameters relevant for evaluation of remedial technologies. The results of the VOC analyses are presented in Table 4-7 and Figure 4-14. Results of general water quality analyses are presented in Table 4-8.

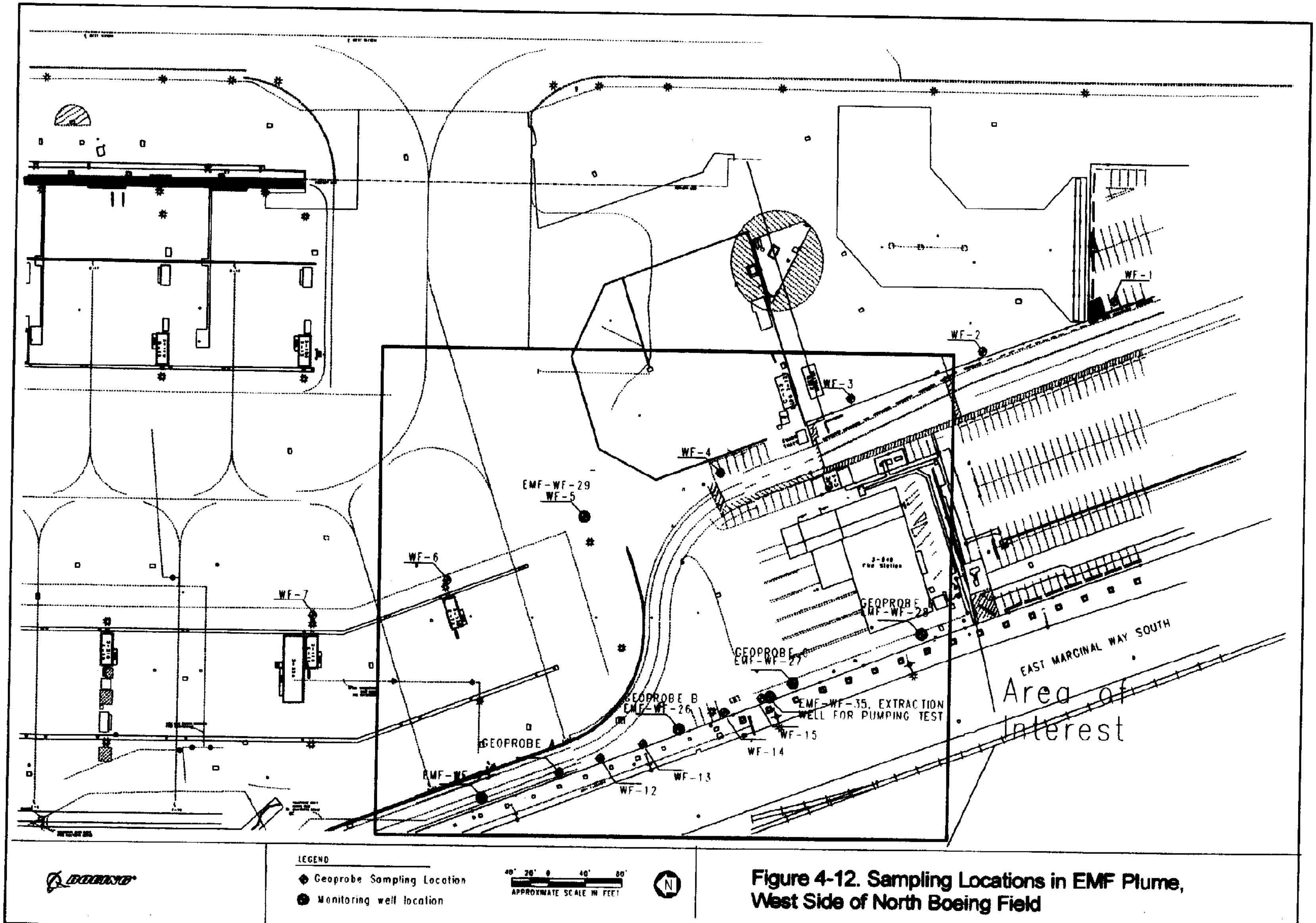

Figure 4-12. Sampling Locations in EMF Plume, West Side of North Boeing Field

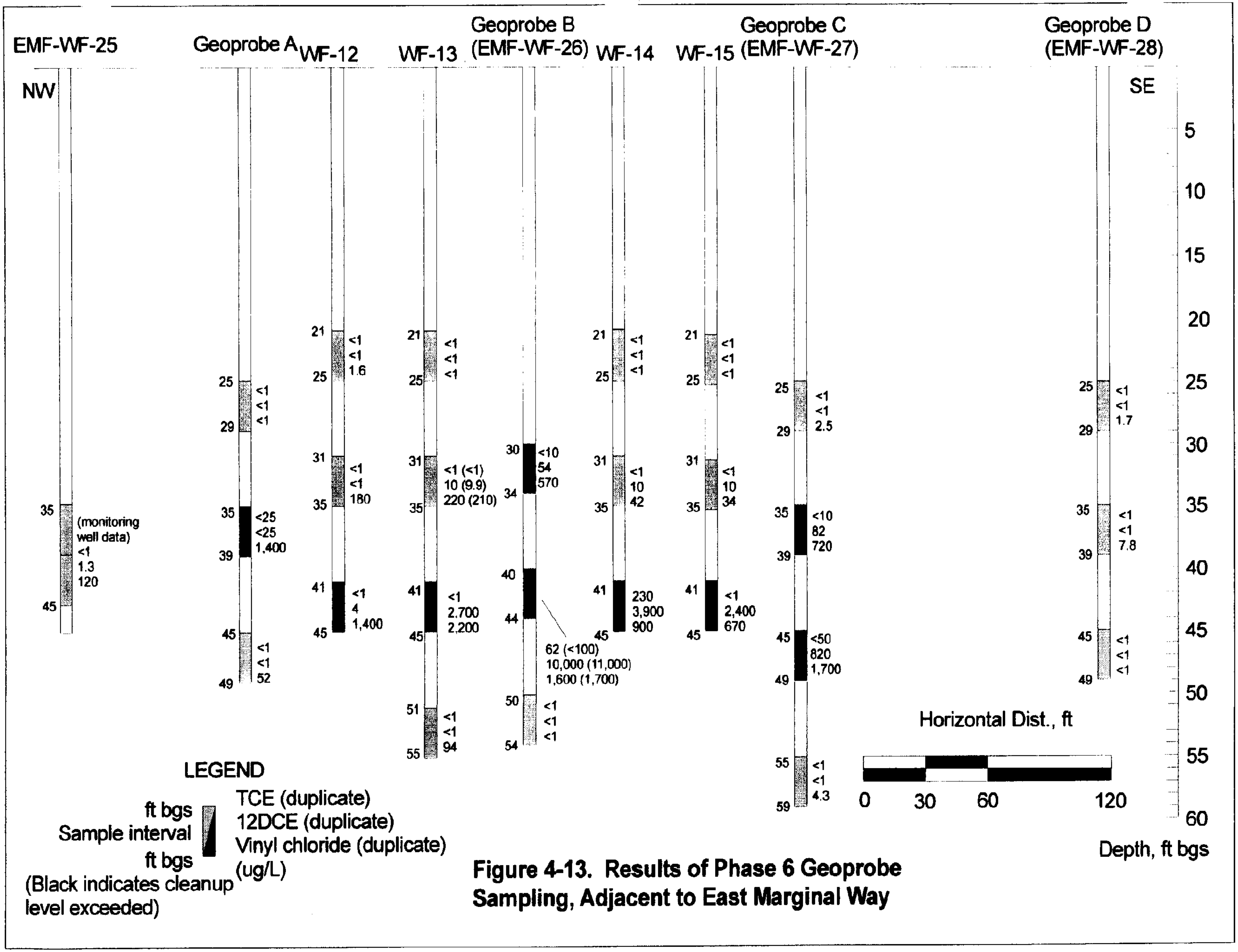

Figure 4-13. Results of Phase 6 Geoprobe Sampling, Adjacent to East Marginal Way

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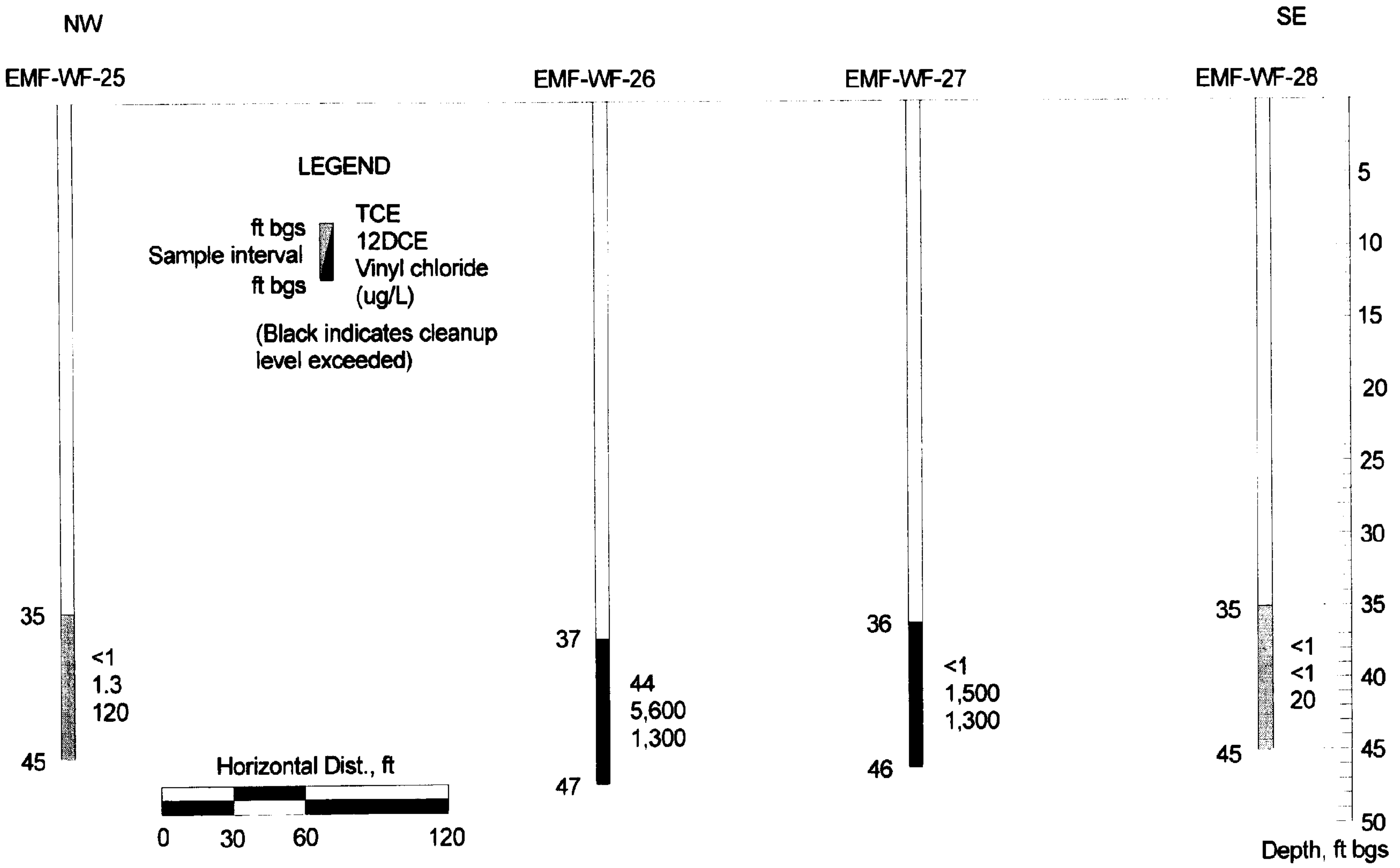

Figure 4-14. Results of Phase 6 Sampling of Monitoring Wells At Western Boundary.

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Table 4-6. Summary of Analytical Results From Phase 6 Geoprobe Sampling.

Location Name & Description	Sampling depth interval, ft bgs	TCE µg/L	c1,2DCE µg/L	Vinyl chloride µg/L
WBF-A, Northern most location (a well was not completed at this location) (28 March 2001)	25 – 29	<1.0	<1.0	<1.0
	35 – 39	<25	<25	**1,400**
	45 – 49	<1.0	<1.0	52
WF-12, Central area of plume (a well was not completed at this location) (29 August 2001)	21 – 25	<1.0	<1.0	1.6
	31 – 35	<1.0	<1.0	180
	41 – 45	<1.0	4	**1,400**
WF-13, Central area of plume (a well was not completed at this location) (29 August 2001)	21 - 25	<1.0	<1.0	<1.0
	31 – 35	<1.0	10	220
	31-35 (dup)	<1	9.9	210
	41 -- 45	<1.0	2,700	**2,200**
	51– 55	<1	<1	94
WBF-B, Central area of plume (completed as Well EMF-WF-26) (28 March 2001)	30 – 34	<10	54	570
	40 – 44	62	10,000	**1,600**
	40 – 44(dup)	<100	11,000	**1,700**
	50 – 54	<1.0	<1.0	<1.0
WF-14, Central area of plume (a well was not completed at this location) (29 August 2001)	21 – 25	<1.0	10	42
	31 – 35	<1.0	<1.0	180
	41 – 45	230	3,900	**900**
WF-15, Central area of plume (a well was not completed at this location) (29 August 2001)	21 - 25	<1.0	10	<1.0
	31 – 35	<1.0	10	34
	41 – 45	<1.0	2,400	**670**
WBF-C, Central area of plume (completed as Well EMF-WF-27) (28 March 2001)	25 – 29	<1.0	<1.0	2.5
	35 – 39	<10	82	**720**
	45 – 49	<50	820	**1,700**
	55 – 59	<1.0	<1.0	4.3
WBF-D, Southern most location, behind Fire Station (completed as Well EMF-WF-28) (28 March 2001)	25 – 29	<1.0	<1.0	1.7
	35 – 39	<1.0	<1.0	7.8
	45 – 49	<1.0	<1.0	<1.0

Shaded cells contain values exceeding cleanup standards. The standards set for protection of aquatic resources and beneficial use of groundwater discharging to the Duwamish Waterway are 2,000 µg/L TCE; 220,000 µg/L c1,2DCE; and 525 µg/L vinyl chloride.

Table 4-7. Summary of Analytical Results, Phase 6 Groundwater Sampling of Wells on West Side of Boeing Field, April 2001.

Well Number and Location	Screened Interval, ft bgs	TCE, μg/L	c1,2DCE, μg/L	Vinyl chloride, μg/L
EMF-WF-25, Northern most location	35 – 45	<1.0	1.3	120
EMF-WF-26, Central area of plume	37 – 47	44	5,600	**1,300**
EMF-WF-27, Central area of plume	36 – 46	<1.0	1,500	**1,300**
EMF-WF-28, Southern most location	35 – 45	<1.0	<1.0	20
EMF-WF-29, Central area of plume, ≈ 200 ft east of other wells	39 – 49	1.4	1,100	**2,500**
EMF-WF-35, Pump test well	35 - 45	<1.0	1,300	260

Shaded cells contain values exceeding cleanup standards. The standards set for protection of aquatic resources and beneficial use of groundwater discharging to the Duwamish Waterway are 2,000 μg/L TCE; 220,000 μg/L c1,2DCE; and 525 μg/L vinyl chloride.

Table 4-8. Results of General Water Quality Analyses from Wells on West Side of Boeing Field (April 2001).

	Concentration, mg/L				
Analyte	**EMF-WF-26**	**EMF-WF-27**	**EMF-WF-28**	**EMF-WF-29**	**Average**
Calcium	48.2	38.1	21.8	25.8	33.5
Iron	18.7	19.1	24.7	21.6	21.0
Magnesium	21.8	19.4	16.7	16.8	18.7
Potassium	8.3	7.3	10.7	7.7	8.5
Sodium	69.2	41.9	86.3	85.6	70.8
Alkalinity (as $CaCO_3$)	250	240	230	250	240
Total dissolved solids	440	330	400	370	380
Chloride	80	30	51	53	54
Nitrate N	<0.010	<0.010	<0.010	<0.010	<0.010
Nitrite N	0.01	0.01	0.031	0.012	
Nitrate plus nitrite N	0.016		0.027		
Sulfate	9.5	10	13	11	10.9
Total Organic Carbon	8.9	7.2	10	7.3	8.4
Dissolved Organic Carbon	6.2	4.8	5.3	4.4	5.2

4.6.1 Grain Size Samples

Soil samples were collected at various depths during drilling in this phase and submitted to a geotechnical laboratory for grain size analysis. The results of the grain size analyses were used to calculate the coefficient of uniformity (C_u, the ratio of the diameter at which 60% of the soil particles are finer, D_{60}, to the diameter at which 10% are finer, D_{10}). The grain size results (presented in Appendix B)indicate that the aquifer materials are generally within the size range of fine sand (0.075 mm to 0.4 mm) and medium sand (0.4 mm to 2.0 mm). The D_{10} values are all within the size range of fine sands, the grain size curves typically indicate about 1percent fine material (silts and clays) in samples. The uniformity coefficients are all low, indicating that the materials are poorly graded (well sorted). Poor grading of sands is indicated by a uniformity coefficient of 6 or less (Terzaghi and Peck, 1967). Based on the results of the grain size analysis, the aquifer materials would be expected to be fairly permeable.

A group of grain size samples collected in the EMF RI (1997) were evaluated for relative comparison with the samples collected on the west side of Boeing Field. The average D_{10} values from samples from the EMF site are about one half the values from samples collected on the west side of Boeing Field. The grain size curves typically indicate about 5 to 10 percent fine material (silts and clays) in samples which is higher than the samples from the west side of Boeing Field. These general characteristics of the grain size distributions provide a qualitative indication the that aquifer materials at the EMF site are a lower permeability than the materials on the west side of Boeing Field.

4.6.2 Aquifer Pumping Test

The observed hydraulic response of the aquifer is consistent with the expected response as a leaky confined aquifer. Based on the these data, the hydraulic conductivity of the aquifer is expected to be approximately 400 ft/day (1.4 x 10^{-1} cm/sec). A leakage response appears to have been observed in the extraction well. This conclusion is based on the shape/inflections of the time vs. drawdown curve and the time ratio (t/t') intercept of the zero residual drawdown (s') in the recovery test. The complete summary of the aquifer pumping test procedures/data analysis and conclusions is provided in Appendix D.

4.6.3 Summary/Interpretation of Phase 6 Data

1) The vertical elevation of the VOC plume remains in a thin stratified plume present at about 35 to 50 ft bgs.

2) VOC data from these locations indicate that the plume width in this area was approximately 300 feet wide (at levels above the AWQCs).

3) Peak concentrations of cis1,2DCE were detected at 11,000 μg /L and vinyl chloride at 2,200 μg/L in Geoprobe samples. The locations where the peak concentrations were detected are not co-located, but they near each other. TCE was also detected at one location at a level of 230 μg/L. Peak concentrations of VOCs detected in monitoring wells in the area are 5,600 μg/L, 1,300 μg/L and 44 μg/L for cis12,DCE, vinyl chloride and TCE respectively. The peak levels detected in monitoring wells are about ½ the peak values detected in Geoprobe samples.

4) The peak levels of vinyl chloride in monitoring wells are about two and one-half times the cleanup standard.

5) The grain size analysis indicates soil samples in the plume area are a well graded fine to medium sand with little silt /fine materials (< 1%). When compared to the grain size curves for soil samples collected at the EMF property (see Table 4-9), the soil in this specific area is coarser (the D_{10} of the grain size curves is about 2 times larger), it is more uniform in size (well graded), and contains less fine materials (< 1% fines versus 5 to 10% fines for soil samples from the EMF property).

6) The aquifer pumping test indicated a hydraulic conductivity of approximately 400 ft/day (1.4×10^{-1} cm/sec). Based on this conductivity, the measured gradient of 0.001 ft/ft and an estimated porosity of 0.25, the predicted groundwater velocity in this area is estimated at 580 ft/year.

Table 4-9. Summary of Grain Size Analysis Results

Western Field Boring	Sample Depth, ft	D_{10}, mm	D_{60}, mm	C_u (D_{60}/D_{10})
EMF-WF-25	25	0.18	0.48	2.7
	40	0.16	0.42	2.6
EMF-WF-26	25	0.15	0.6	4
	45	0.2	0.55	2.8
EMF-WF-29	15	0.25	0.52	2.1
	35	0.23	0.48	2.1
EMF-WF-28	20	0.26	0.6	2.3
	20	0.26	0.6	2.3
	20	0.26	0.6	2.3
	30	0.18	0.55	3.1
	40	0.23	0.55	2.4
	45	0.2	0.55	2.8
	Average	0.21	0.54	2.63
EMF Site Boring	**Sample Depth, ft**	**D_{10}, mm**	**D_{60}, mm**	**C_u (D_{60}/D_{10})**
SB EMF24	25	0.1	0.35	3.50
SB EMF25	7.5	0.12	0.4	3.33
SB EMF25	17	0.08	0.25	3.13
SB EMF25	25	0.15	1	6.67
	Average	0.11	0.50	4.16

5.0 Evaluation of Data/Investigation Results

The additional data collected from the site requires a revision to the conceptual model of the site conditions and VOC plume distribution. The added data indicates that the VOC plume extends across Boeing Field to the western boundary along East Marginal Way. The VOC plume is present in a relatively narrow, stratified plume that follows the regional groundwater gradient from the EMF site. The highest concentrations of VOCs are found at about 40 to 50 feet bgs, above a silty zone that appears to prevent further downward migration. Vinyl chloride is the only VOC present above AWQCs at the downgradient boundary of the existing sampling. Maximum vinyl chloride concentrations in monitoring wells at the downgradient boundary are approximately two and half times the AWQC.

5.1 Quarterly Monitoring Data

The quarterly monitoring data (presented in Appendix D) have shown consistent reductions in all of the target VOCs since the start of site remediation. For the group of monitoring wells located directly within the central on-site VOC plume area the average reductions (all wells combined) for TCE, DCE and vinyl chloride are 88%, 79% and 71%, respectively.

5.2 Hydraulic Conductivity and Groundwater Transport Velocity

The aquifer pumping test indicated a hydraulic conductivity of approximately 400 ft/day , based on this conductivity and other measured/estimated parameters (gradient of 0.001, porosity of 0.25) the predicted groundwater velocity in the area near the west side of Boeing Field is estimated at 580 ft/year. The gradient back at the EMF site has been measured at 0.004 ft/ft and the average gradient across Boeing Field has been measured at 0.002 ft/ft.

The hydraulic conductivity at the EMF property is estimated to be lower than the measured value from the west side of Boeing Field based on the differences in the grain size distributions. An estimate of the groundwater transport velocity at the EMF site is approximately 200 ft/yr.

The contaminant transport velocity is expected to be less than the groundwater velocity because of adsorption to soil. An estimate of the contaminant retardation factor (ratio of groundwater velocity to contaminant transport velocity) is about a factor of 1.4. This is based on the K_{oc} for cis1,2-DCE of 65 and a fraction organic carbon of 0.001 in the soil. Using this retardation factor the expected VOC transport velocity is in the range of 140 to 400 ft/year.

5.3 VOC Plume

Extensive sampling has been completed to locate and define the vertical/horizontal position of the downgradient VOC plume (~ 70 discrete Geoprobe samples and 10 new monitoring wells). The analytical data indicate that the VOC plume shows very little spreading/dispersion in the vertical and horizontal directions as it has migrated in a downgradient direction for approximately 2,200 ft. The projected path of the VOC plume across Boeing Field is depicted in Figure 5-1. The sampling locations in Figure 5-1 with concentrations above the site cleanup goals are depicted in red. The VOC concentrations decrease significantly within this sampled downgradient distance (more than an order of magnitude).

Figure 5-1. Estimated Path of VOC Plume from EMF Site

The approximate width of the VOC plume at levels above the cleanup standards (AWQCs) is about 300 ft (transverse to the direction of flow) and the approximate width at levels above detection limits is estimated at about 600 ft.

Since the VOC plume does not spread in this transport distance, the observed concentration reductions are believed to be the result of degradation by reductive dechlorination. The results of the general water quality analyses are consistent with this expected anaerobic dechlorination mechanisms. The concentrations of nitrite and iron are indicative of reducing conditions and the dissolved organic carbon concentration suggest the presence of an organic substrate to serve as an electron donor. As a result, the observed VOC concentrations would be expected to decrease further as contaminants travel in the direction towards the Duwamish Waterway.

5.4 VOC Attenuation Processes

The two primary processes expected to attenuate the VOC concentration in the plume are degradation and dispersion. The expected impacts of those processes are discussed in the following sections.

5.4.1 Degradation

The typical degradation process for TCE via reductive dechlorination is depicted in Figure 5-2. The site geochemical conditions are conducive for this degradation process and each of the daughter products (through ethene and including increased chloride levels) have been measured within the VOC plume area.

The rate of VOC concentration reduction observed in the plume has been evaluated using first-order degradation modeling. The objectives of this analysis are to:

1) Determine if the observed plume distribution is consistent with a first order degradation process .
2) Derive rate constants for the degradation process.
3) Provide a tool/predictive model for estimating downgradient concentrations beyond the zone where monitoring structures are in place.

The calibration of the degradation modeling basically is a curve fitting process where the measured spatial distribution of the VOCs (i.e., concentration reduction from the source in the downgradient direction) is used to calculate the degradation rate constants using the concentration data and the contaminant transport velocity. The data used for the degradation modeling are the peak VOC concentrations detected along several transects of the plume from the source area to East Marginal Way. A reasonable peak concentration at the source area has been set at 250,000 μg/L. The highest concentration detected in the source was 1,007,000 μg/L (~TCE saturation). However, a lower value is used in the degradation modeling because multiple Geoprobe samples in the immediate area indicated a highest measured value of 190,000 μg/L (pre-1997 before any remedial measures were implemented). The peak concentration detected (near TCE solubility) is expected to be representative of a very thin vertical interval and an average value is believed to be more appropriate for the model calibration.

The degradation modeling results are presented in Figures 5-3 and 5-4. The site data and the degradation modeling results in Figure 5-3 indicate that the primary VOC to be degraded from the EMF property downgradient is cis1,2-DCE (i.e., almost all of the TCE has been degraded before reaching the property boundary). Peak cis1,2-DCE concentrations are reduced from ~ 109,000 μg/L (well EMF MW-22, January 2001)

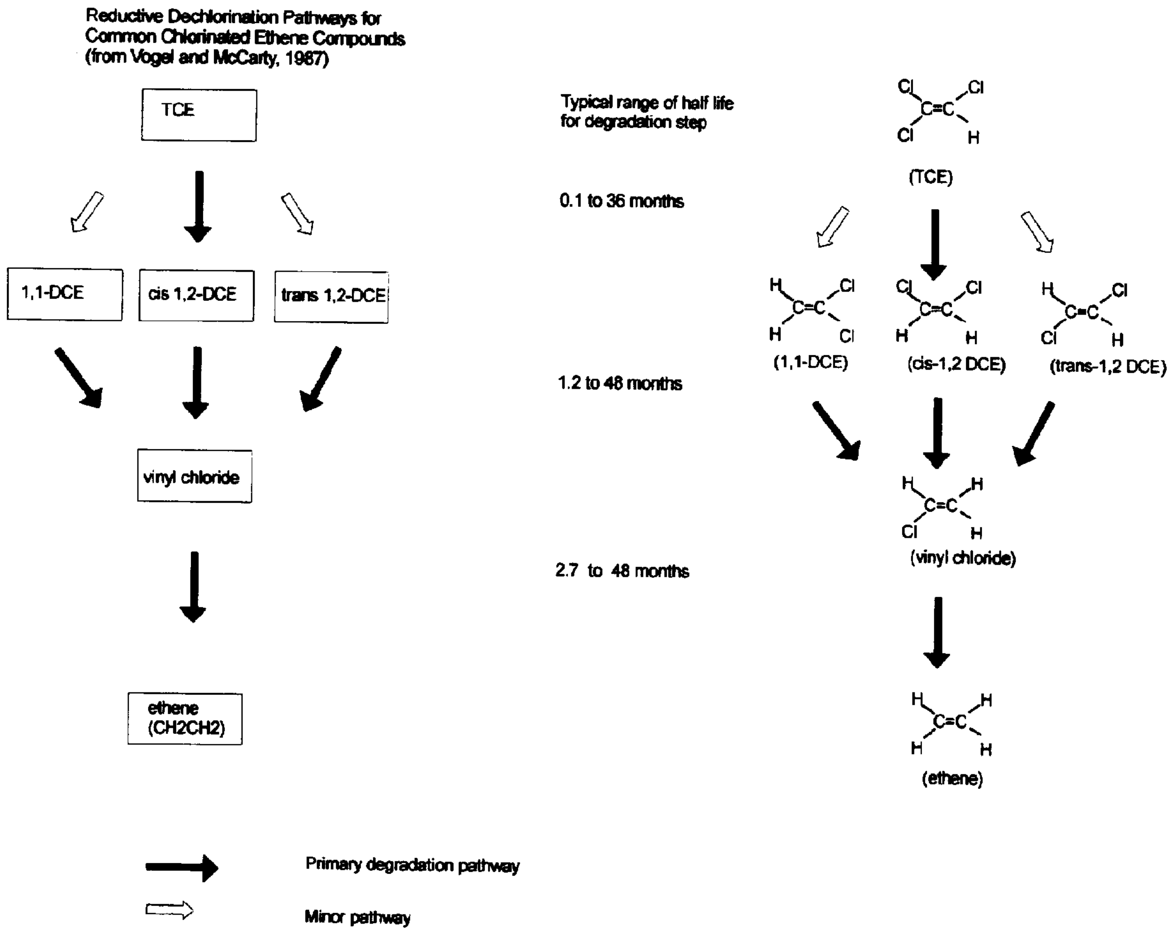
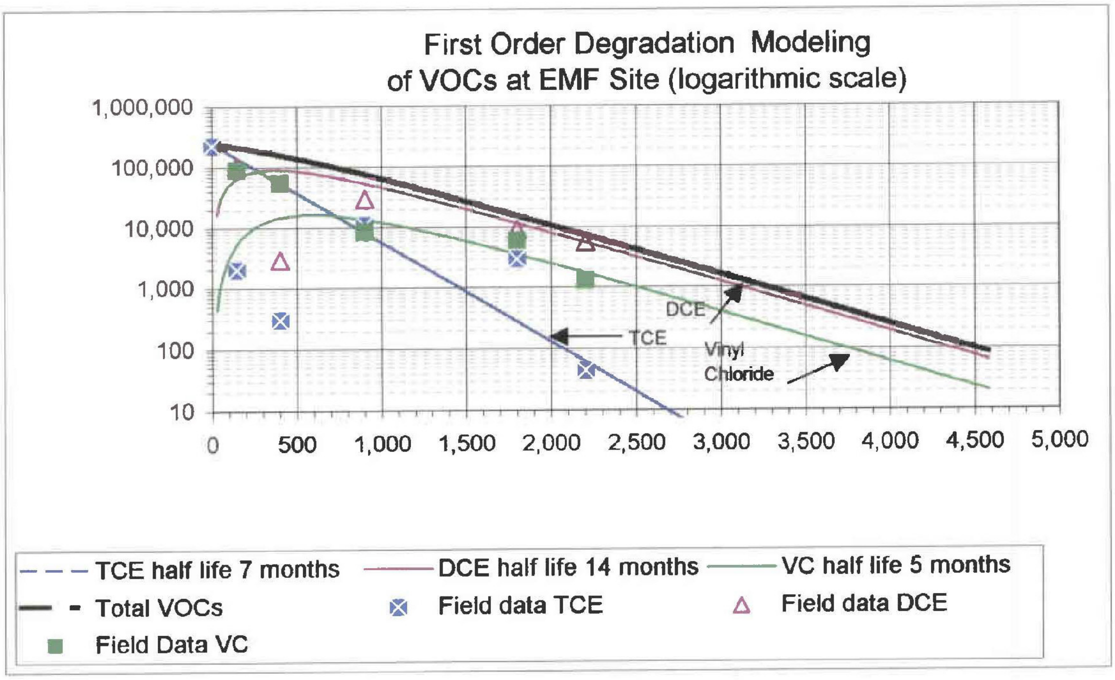


Figure 5-2
Primary Degradation Pathways of Chlorinated Ethenes by by Reductive Dechlorination



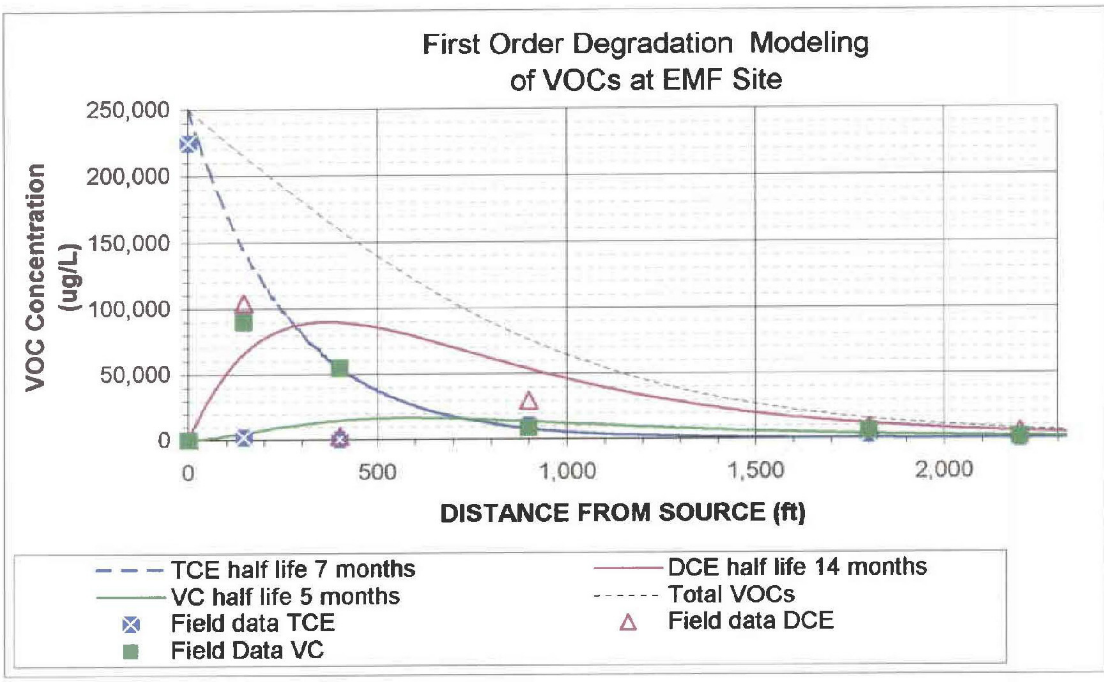
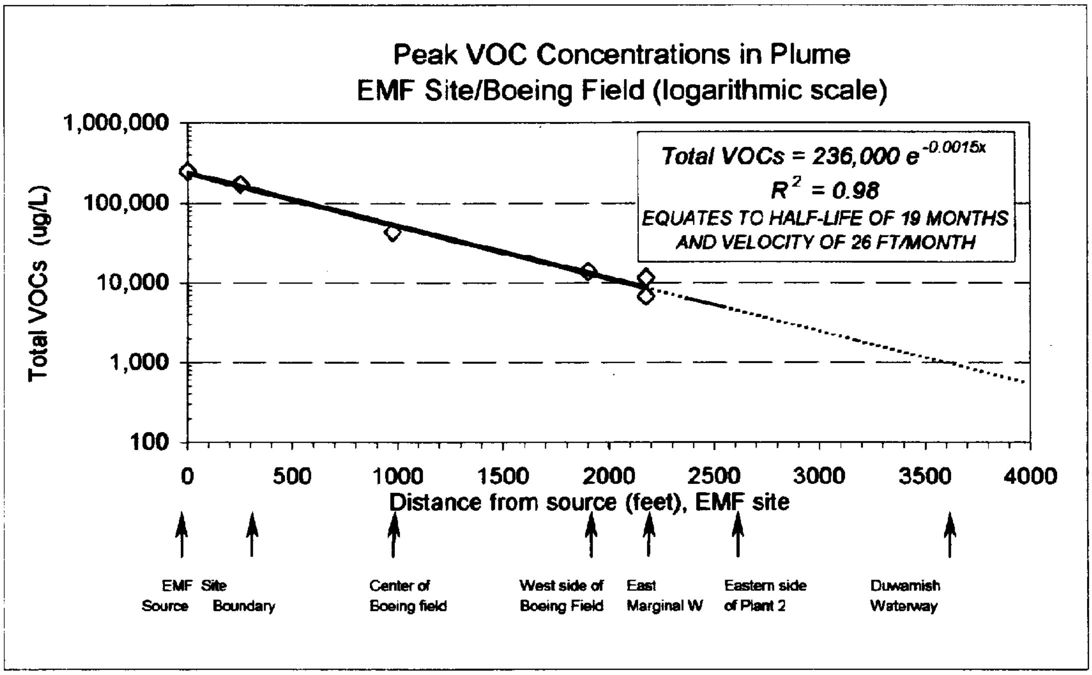


Figure 5-3 First Order Degradation Modeling
TCE and Daughter Products



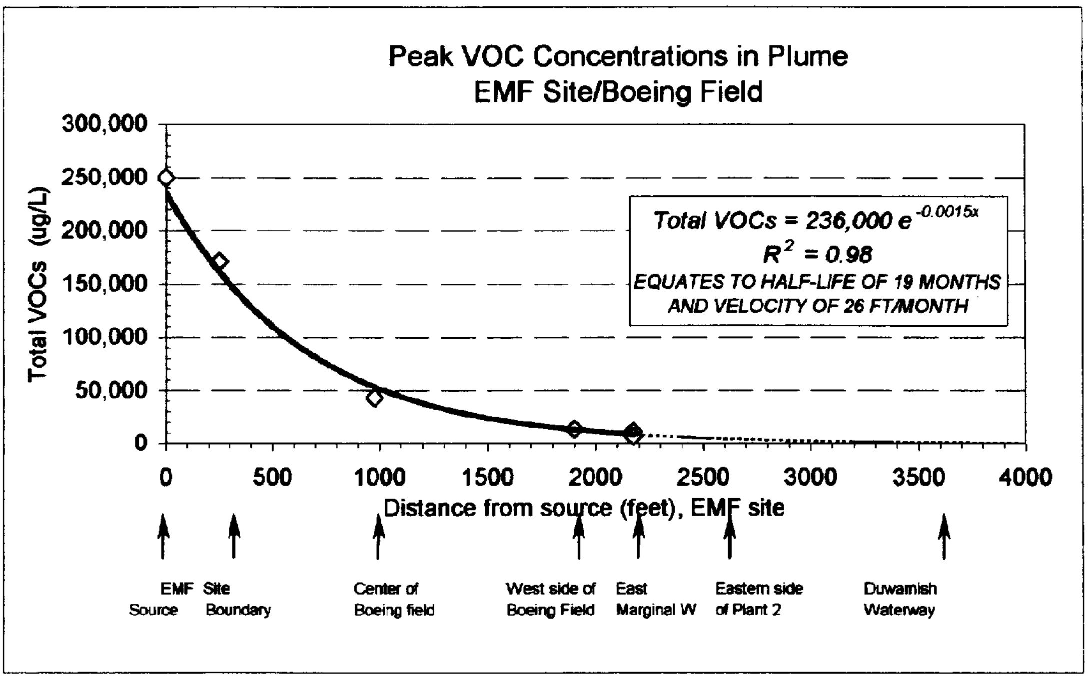


Figure 5-4 First Order Degradation Modeling of Total VOCs

down to ~4,000 μg/L (a factor of 27 reduction)(well EMF-MW-26, October 2001). The daughter product derived for the cis1,2-DCE degradation is vinyl chloride.

In this same groundwater transport range, the peak vinyl chloride concentrations are reduced from ~23,000 μg/L down to 1,300 μg/L (a factor of 17 reduction). This measured vinyl chloride reduction occurs over same interval that the cis1,2-DCE degradation has generated a larger amount (mass and concentration) of vinyl chloride. Each mole of cis1,2-DCE degraded creates one mole of vinyl chloride (109,000 μg/L of cis1,2-DCE degrades to 69,800 μg/L of vinyl chloride). These data indicate that complete dechlorination to ethene is occurring and that the degradation of cis1,2-DCE appears to be a rate limiting step (vinyl chloride is degrading faster than it is generated by the cis1,2-DCE degradation).

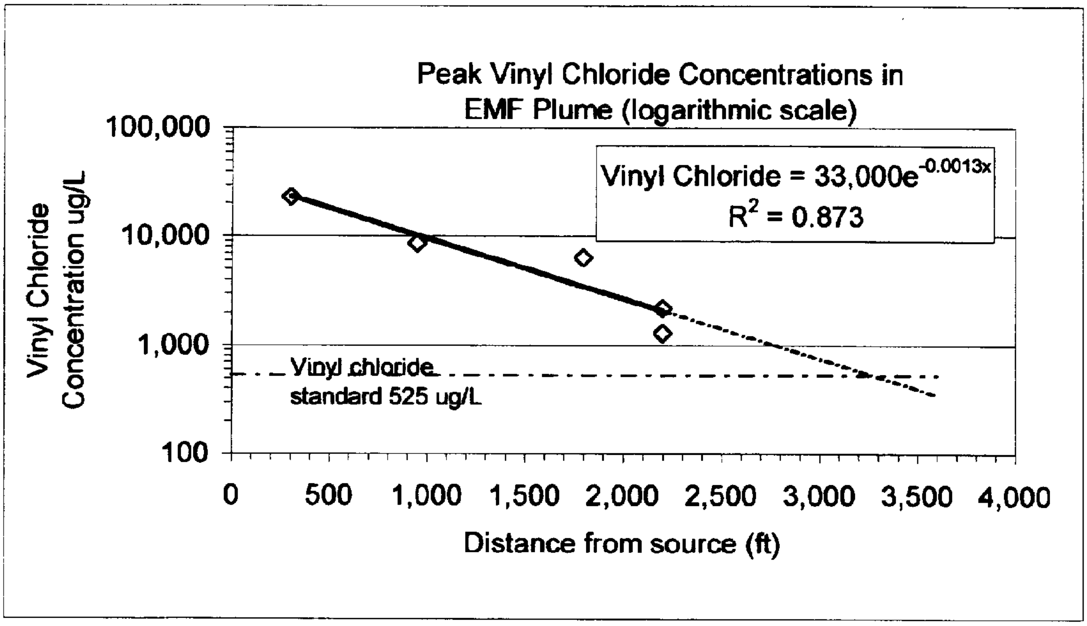
The laboratory results (shown in Tables of Section 4) along with Figure 5-3 indicate substantial field variability/heterogeneity in the degradation processes. Different portions of a each plume transect may have varying fractions of TCE, cis1,2-DCE and vinyl chloride. Some of the measurements closer to the EMF property indicate a more rapid TCE degradation than some of the downgradient data. A simpler presentation of the degradation processes is as a combined, i.e, total VOCs, removal process. Those modeling results are presented in Figure 5-4 and they show a much clearer fit of the field data to the model predicted concentrations based on degradation of the total VOCs present.

The same analysis can be applied to the vinyl chloride data by itself (ignoring the TCE and cis1,2-DCE degradation that creates the vinyl chloride). These results are presented in Figure 5-5 which shows a general approximation to a first order degradation process. These results also show much more scatter of the field data around the model predicted results (as indicated by a lower R^2 of the regression used to calibrate the model predictions to the field data). This is expected because this analysis (vinyl chloride by itself) does not explicitly include the cis,2-DCE degradation as a process step (which is generating vinyl chloride as the daughter product). However, the general trend of vinyl chloride attenuation (as observed in the field data) does effectively include all vinyl chloride generated from cis1,2-DCE degradation. The generation of the vinyl chloride by cis1,2-DCE degradation is implicitly included in the derived rate constant (the reduced exponent represents a slower decay rate because of the mass that is being created).

5.4.2 Tidally Enhanced Dispersion

In addition to biological degradation, the concentration of VOCs discharged to the Duwamish Waterway will also be significantly reduced due to dispersion and dilution caused by tidal effects before the groundwater discharges to the river. The level of the Duwamish Waterway in the vicinity of the site varies due to tidal effects. These tidal fluctuations in river level result in periodic (approximately once every 6 hours) reversals in the groundwater gradient near the river. At times when the gradient is reversed, there is an inflow of water from the river into the shallow aquifer. This inflow and outflow of river water results in mixing and dilution of the groundwater plume near the boundary with the river.

The effect of this tidally-induced mixing was evaluated using a groundwater transport model of near-shore tidal mixing. The model input used average tidal characteristics (amplitude and period) from Seattle harbor. The results of the modeling are shown in Figure 5-6. These results show that the dilution effects would be expected to extend inward to approximately 100 ft from the river boundary and that the net dilution of the plume just inward from the boundary would be a factor of 50 (e.g., an upgradient groundwater concentration of 100 μg/L would be reduced to 2 μg/L at the point of discharge to the river).



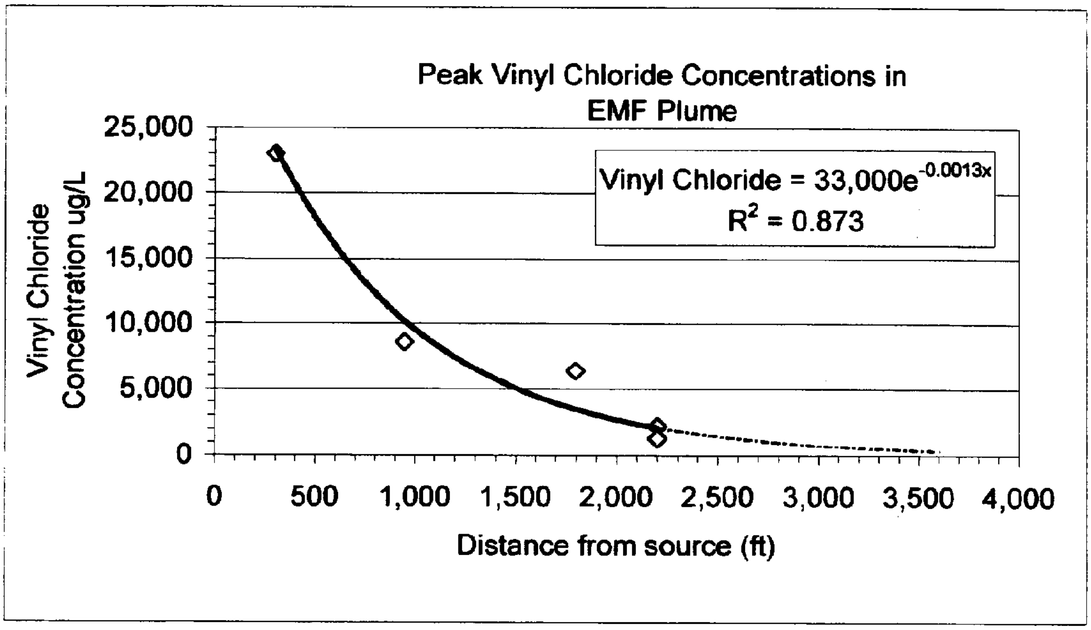
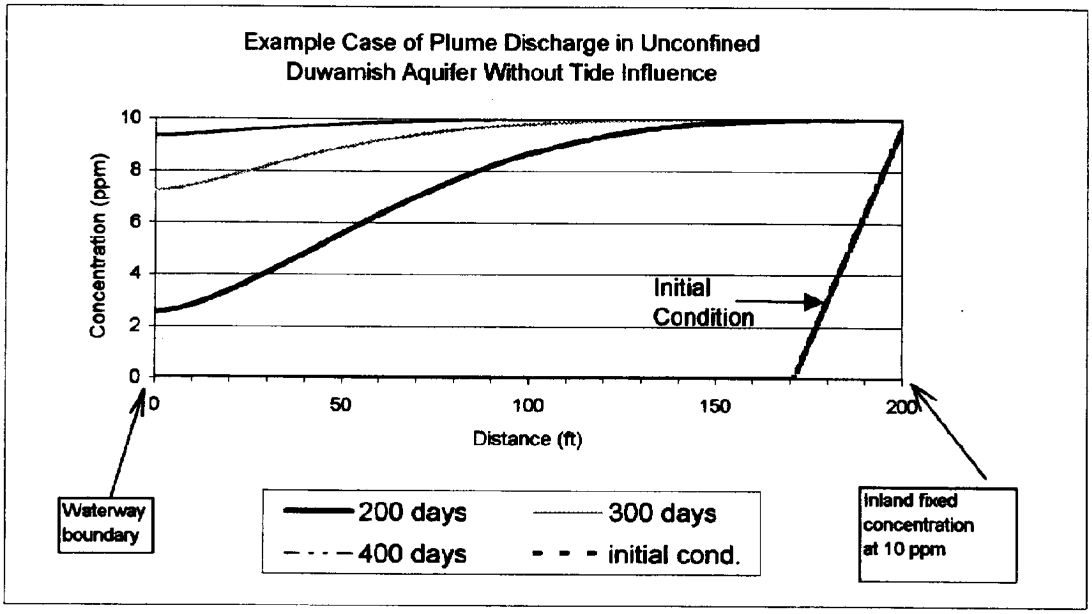


Figure 5-5 First Order Degradation Modeling for Vinyl Chloride Only



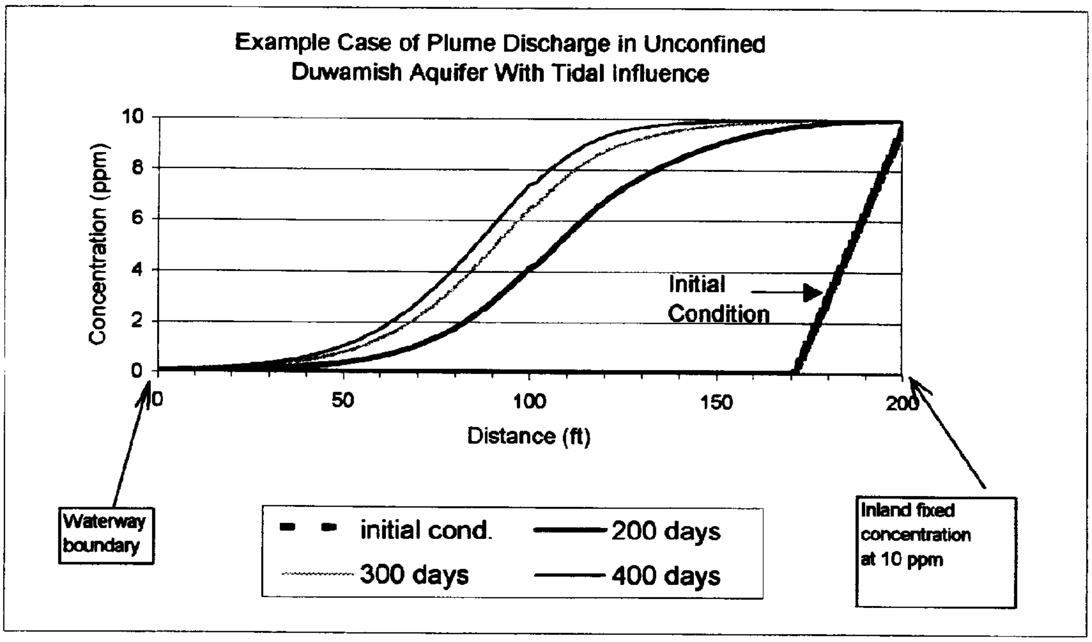
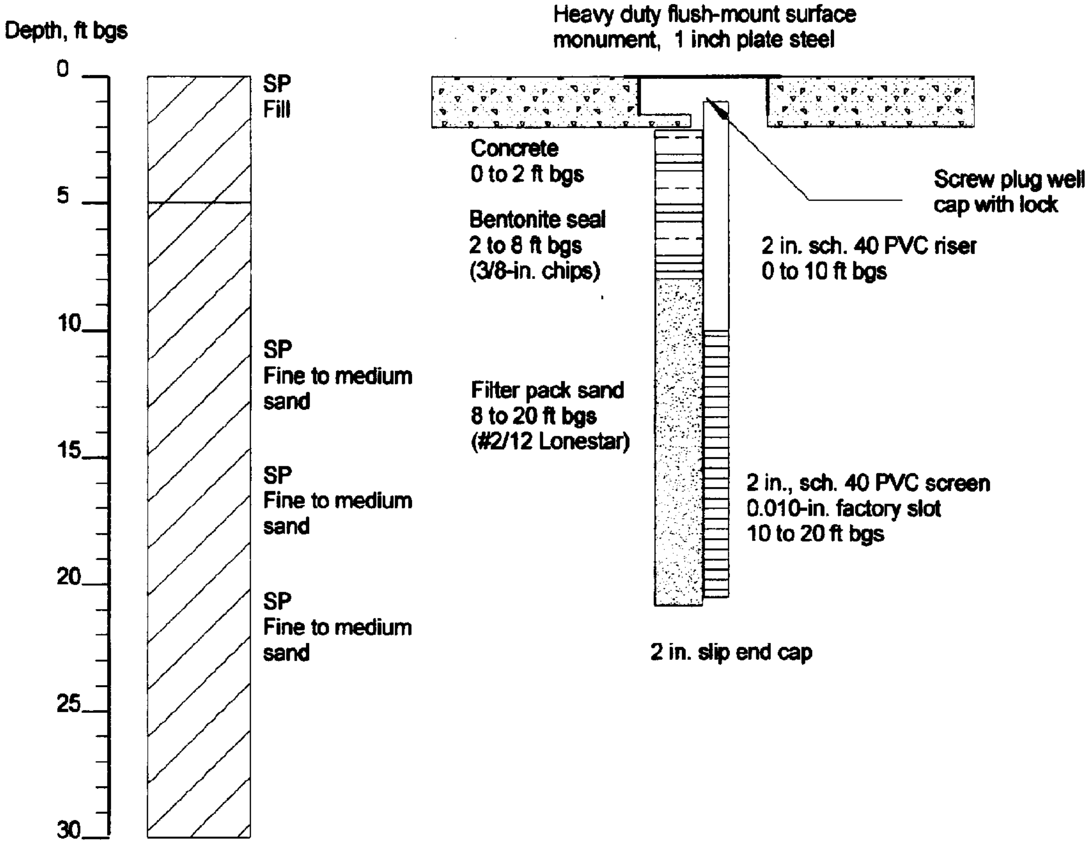


Figure 5-6 Model Predicted Dilution in Groundwater from Tdally Enhanced Dispersion

Note that this tidally induced dispersion does not impact the VOC mass flux to the Waterway but rather dilutes the discharge concentration because of the increased water flux in the tidal flushing zone. The evaluation of the effects of tidally-induced mixing is described in more detail in Appendix F. Groundwater monitoring near the boundary of the river at various locations along the Duwamish Waterway has demonstrated the tidal influence and the net transport of saline waters into the near-shore groundwater zone. These field data demonstrate this tidal dispersion effect in the groundwater zone prior to the point of discharge to the river.

Appendix A – Geologic Boring Logs



Drilling date: 06/21/01

Driller: Cascade Drilling

6 in. borehole, 4-1/4-in.
I.D. hollow-stem augers

Total depth: 20.25 ft

Location and elevation:
Not surveyed

Development: Surge and pump,
Approx. 25 gallons removed.
Pumped at ~1 gpm with whale pump.

Project Performance Corporation
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Bellevue, WA 98008
(425) 643-4634 fax (425) 649-0643

REVISION NO.:	DATE:	ACAD FILE:
0	06/21/01	11-SR.SKF

Monitoring Well 11SR

DRAWN:	CLIENT:	PROJECT NO.:
JJD	Boeing	1214-115
CHECKED:	LOCATION:	FIGURE:
TJM	EMF Site	-

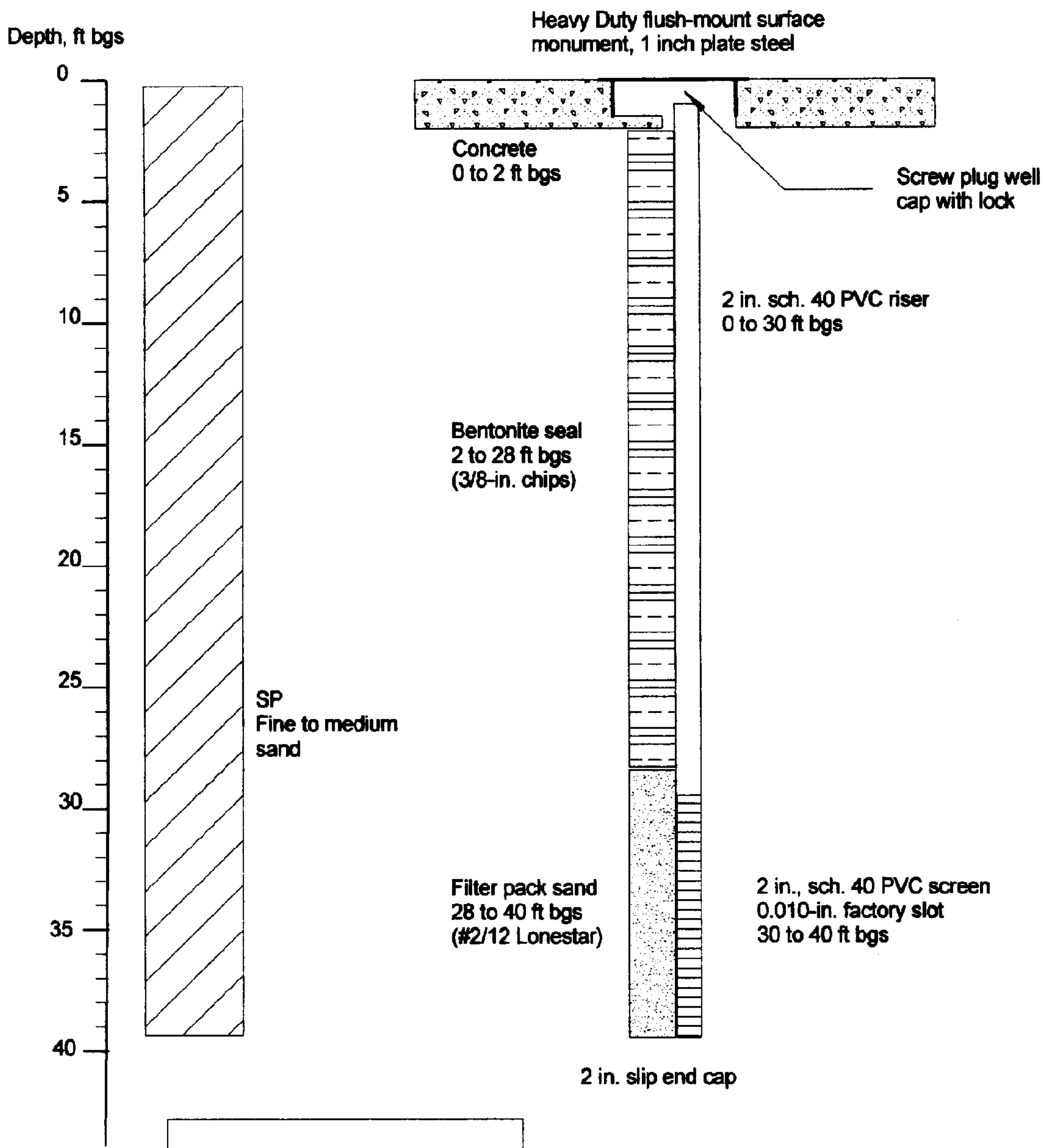
Project Performance CORPORATION

GEOLOGIC BORING LOG

PROJECT: EMF earthquake damage	**JOB NO.** 1214-115	**SHEET 1** Of	**BORING NO.** 11 Sr
PROJECT LOCATION: EMF Site Boeing Field	**BORING LOCATION:** 11S r (replacement)		**TOTAL DEPTH** 21.5 ft
		BEGUN: 6/21 0720	
DRILL CONTRACTOR: Cascade	**GEOLOGIST:** TJM	**FINISHED:** 6/21 0840	
DRILL RIG:	**DRILLER:** Brian Gose	**GROUND ELEV.:**	
HOLE SIZE: 4 ¼ in. ID augers, 6 inch hole	**WEATHER:** clear & dry	**GROUND WATER (DEPTH/ELEV.):** ~ 7' bgs	
DRILLING METHOD: HS Auger	**DRILLING FLUID/SOURCE:**	**TOP OF ROCK (DEPTH/ELEV.):**	

DEPTH	SAMPLE TYPE/NO. & DEPTH	BLOW COUNT PER 6 IN.	PERCENT RECOVERY	NOTES: (PRODUCT, ODOR, OVA READING, ETC.)	USCS LOG	STRATIGRAPHIC DESCRIPTION
				No samples until 10'		11 S sounded at 20.25' bgs (to be replaced)
10'	SS 10' to 11.5' NA	3 5 5	50%		SP	Fine to medium sand, tan w/ white and black flecks to black sand at 11 ½ ft w/ more silt
15'	SS 15' to 16.5' NA	7 12 10	80%		SP	Fine to medium sand, black w/ red and white Flecks
20'	SS 20' to 21.5'	3 5 8	50%		SP	SAA appears to be heave. Waste soil Sample #11 SR drum 1. Well set at 20' Screen 10 slot from 10' to 20' Sand 8' to 20' Riser 0 to 10'; flush mount 3 bags Lonestar 2/12 sand 3 bags Pure Gold 3/8 in. bentonite chips

SAMPLE TYPES
SS=SPLIT SPOON, ST=SHELBY TUBE
R= ROCK CORE, O=OTHER



Drilling date: 06/21/01

Driller: Cascade Drilling

6 in. borehole, 4-1/4-in. I.D. hollow-stem augers

Total depth: 39.4 ft

Location and elevation: Not surveyed

Development: Surge and pump, Approx. 25 gallons removed. Pumped at ~1 gpm with whale pump.

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16935 SE 39th St.
Bellevue, WA 98008
(425) 643-4634 fax (425) 649-0643

REVISION NO.: 0	DATE: 06/21/01	ACAD FILE: 11-DR.SKF

Monitoring Well 11DR

DRAWN: JJD	CLIENT: Boeing	PROJECT NO.: 1214-115
CHECKED: TJM	LOCATION: EMF Site	FIGURE: -

Project Performance Corporation

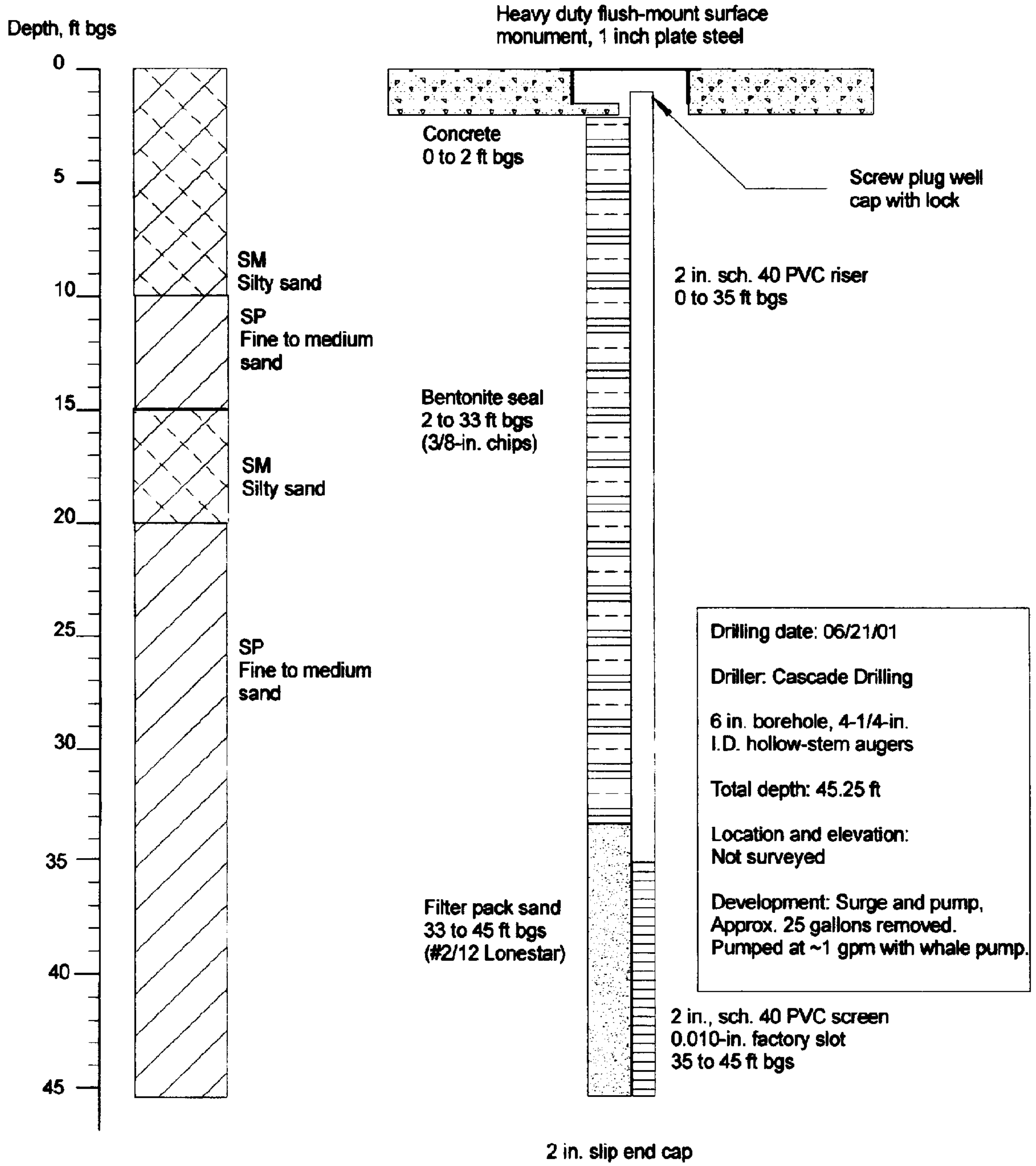
GEOLOGIC BORING LOG

PROJECT: EMF earthquake damage repair	**JOB NO.** 1214-115	**SHEET 1** Of 1	**BORING NO.** 11 Dr
PROJECT LOCATION: EMF Site Boeing Field	**BORING LOCATION:** 11D r (replacement)		**TOTAL DEPTH** 41.5 ft
		BEGUN: 6/21 0900	
DRILL CONTRACTOR: Cascade	**GEOLOGIST:** TJM	**FINISHED:** 6/21 1110	
DRILL RIG:	**DRILLER:** Brian Gose	**GROUND ELEV:**	
HOLE SIZE: 4 ¼ in. ID augers, 6 inch hole	**WEATHER:** clear & dry	**GROUND WATER (DEPTH/ELEV.):** ~ 7.5 ft bgs	
DRILLING METHOD: HS Auger	**DRILLING FLUID/SOURCE:**	**TOP OF ROCK (DEPTH/ELEV.):**	

DEPTH	SAMPLE TYPE/NO. & DEPTH	BLOW COUNT PER 6 IN.	PERCENT RECOVERY	NOTES: (PRODUCT, ODOR, OVA READING, ETC.)	USCS LOG	STRATIGRAPHIC DESCRIPTION
				No samples until 25'		11 D sounded at 39.4' ft bgs (to be replaced)
25'	SS 25' to 26.5' NA	10 8 14	100%	Log from 11 SR is ~ 10' north	SP	Fine to medium sand, black w/ red and white Flecks; saturated.
30'	SS 30' to 31.5' NA	5 8 12	NR		SP	SAA
35'	SS 35' to 36.5' NA	6 6 10	NR		SP	SAA
40'	SS 40' to 41.5' NA		0			No recovery. Set well at 40' Screen 10 slot 30' to 40' Sand 2/12 28' to 40' Grout 2' to 28' Concrete 0 to 2' 3 bags Lonestar 2/12 sand 6 bags bentonite chips

SAMPLE TYPES
SS=SPLIT SPOON, ST=SHELBY TUBE
R= ROCK CORE, O=OTHER

KCSlip4 43977



Drilling date: 06/21/01

Driller: Cascade Drilling

6 in. borehole, 4-1/4-in. I.D. hollow-stem augers

Total depth: 45.25 ft

Location and elevation: Not surveyed

Development: Surge and pump, Approx. 25 gallons removed. Pumped at ~1 gpm with whale pump.

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Bellevue, WA 98008
(425) 643-4634 fax (425) 649-0643

REVISION NO.: 0	DATE: 06/21/01	ACAD FILE: 12-DR.SKF

Monitoring Well 12DR

DRAWN: JJD	CLIENT: Boeing	PROJECT NO.: 1214-115
CHECKED: TJM	LOCATION: EMF Site	FIGURE: -

KCSlip4 43978

Project Performance CORPORATION

GEOLOGIC BORING LOG

PROJECT: EMF earthquake damage	**JOB NO.** 1214-115	**SHEET 1** Of 2	**BORING NO.** 12 Dr
PROJECT LOCATION: EMF Site Boeing Field	**BORING LOCATION:** 12D r (replacement)		**TOTAL DEPTH** 46.5 ft
		BEGUN: 6/21 1230	
DRILL CONTRACTOR: Cascade	**GEOLOGIST:** TJM	**FINISHED:** 6/21 1500	
DRILL RIG:	**DRILLER:** Brian Gose	**GROUND ELEV.:**	
HOLE SIZE: 4 ¼ in. ID augers, 6 inch hole	**WEATHER:** clear & dry	**GROUND WATER (DEPTH/ELEV.):** 8.7 ft	
DRILLING METHOD: HS Auger	**DRILLING FLUID/SOURCE:**	**TOP OF ROCK (DEPTH/ELEV.):**	

DEPTH	SAMPLE TYPE/NO. & DEPTH	BLOW COUNT PER 6 IN.	PERCENT RECOVERY	NOTES: (PRODUCT, ODOR, OVA READING, ETC.)	USCS LOG	STRATIGRAPHIC DESCRIPTION
				PID ppmv		12 D sounded at 45.25 ft 6 in. asphalt Hand dug to ~ 5 ft to clear utilities
10'	SS 10' to 11.5' NA	6 7 7	100%	0	SP	Top 6" brown silty sand; saturated Next 12" black fine to medium sand w/ red/white flecks
15'	SS 15' to 16.5' NA	6 6 8	100%	0	SM/ SP	Top 6" layer SP (SAA); then 12" silty fine sand
20"	SS 20' to 21.5' NA	10 6 9	90%	0	SP	Fine to medium sand, black w/ red/white flecks
25'	SS 25' to 26.5' NA	8 11 11	~ 5%	0	SP	SAA; small recovery
30'	SS 30' to 31.5'	10 18 20	90%	0	SP	SAA
35'	SS 35' to 36.5' NA	12 15 14	5%	0	SP	SAA; small recovery
40'	SS 40' to 41.5'	5 9	80%	0	SP	SAA

SAMPLE TYPES
SS=SPLIT SPOON, ST=SHELBY TUBE
R= ROCK CORE, O=OTHER

Project Performance Corporation **Geologic Boring Log**

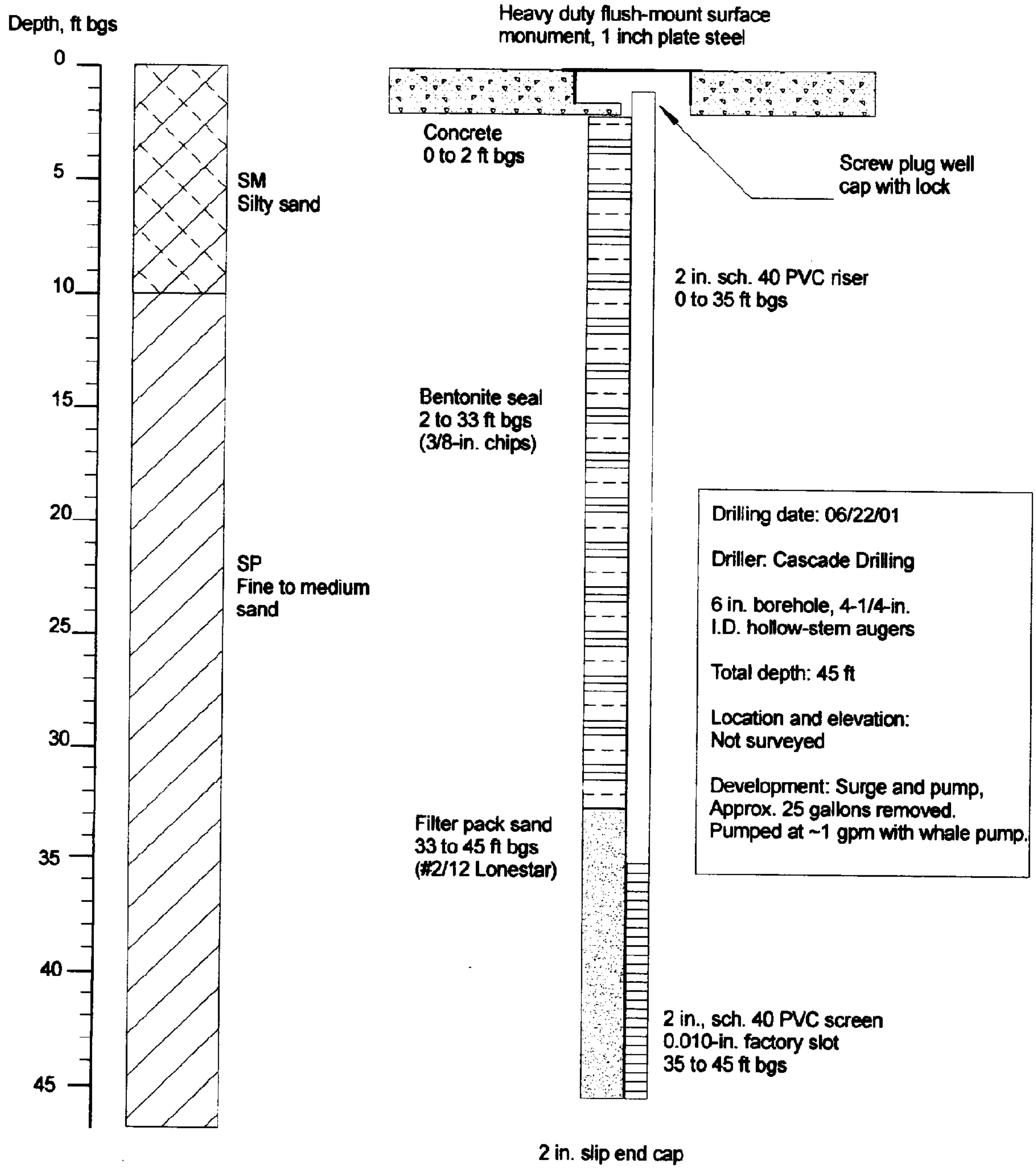
Boring: 12DR

DEPTH	SAMPLE TYPE/NO. & DEPTH	BLOW COUNT PER 6 IN.	PERCENT RECOVERY	NOTES: (PRODUCT, ODOR, OVA READING, ETC.)	USCS LOG	STRATIGRAPHIC DESCRIPTION
	NA	11				
45'	SS 45' to 46.5' NA	9 9 10	90%	0	SP/SM	SAA grading finer

SAMPLE TYPES
SS=SPLIT SPOON, ST=SHELBY TUBE
R= ROCK CORE, O=OTHER

KCSlip4 43980

SEA410510



Drilling date: 06/22/01

Driller: Cascade Drilling

6 in. borehole, 4-1/4-in.
I.D. hollow-stem augers

Total depth: 45 ft

Location and elevation:
Not surveyed

Development: Surge and pump,
Approx. 25 gallons removed.
Pumped at ~1 gpm with whale pump.

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Bellevue, WA 98008
(425) 643-4634 fax (425) 649-0643

REVISION NO.:	DATE:	ACAD FILE:
0	06/22/01	13-DR.SKF

Monitoring Well 13DR

DRAWN:	CLIENT:	PROJECT NO.:
JJD	Boeing	1214-115
CHECKED:	LOCATION:	FIGURE:
TJM	EMF Site	-

KCSlip4 43981

SEA410511

Project Performance CORPORATION

GEOLOGIC BORING LOG

PROJECT: EMF earthquake damage	**JOB NO.** 1214-115	**SHEET 1** Of 2	**BORING NO.** 13 Dr
			TOTAL DEPTH 46.5 ft
PROJECT LOCATION: EMF Site Boeing Field	**BORING LOCATION:** 13Dr (replacement)	**BEGUN:** 6/22 0700	
DRILL CONTRACTOR: Cascade	**GEOLOGIST:** TJM	**FINISHED:** 6/22 0945	
DRILL RIG:	**DRILLER:** Brian Gose	**GROUND ELEV.:**	
HOLE SIZE: 4 ¼ in. ID augers, 6 inch hole	**WEATHER:** cloudy & dry	**GROUND WATER (DEPTH/ELEV.):** 8.3 ft	
DRILLING METHOD: HS Auger	**DRILLING FLUID/SOURCE:**	**TOP OF ROCK (DEPTH/ELEV.):**	

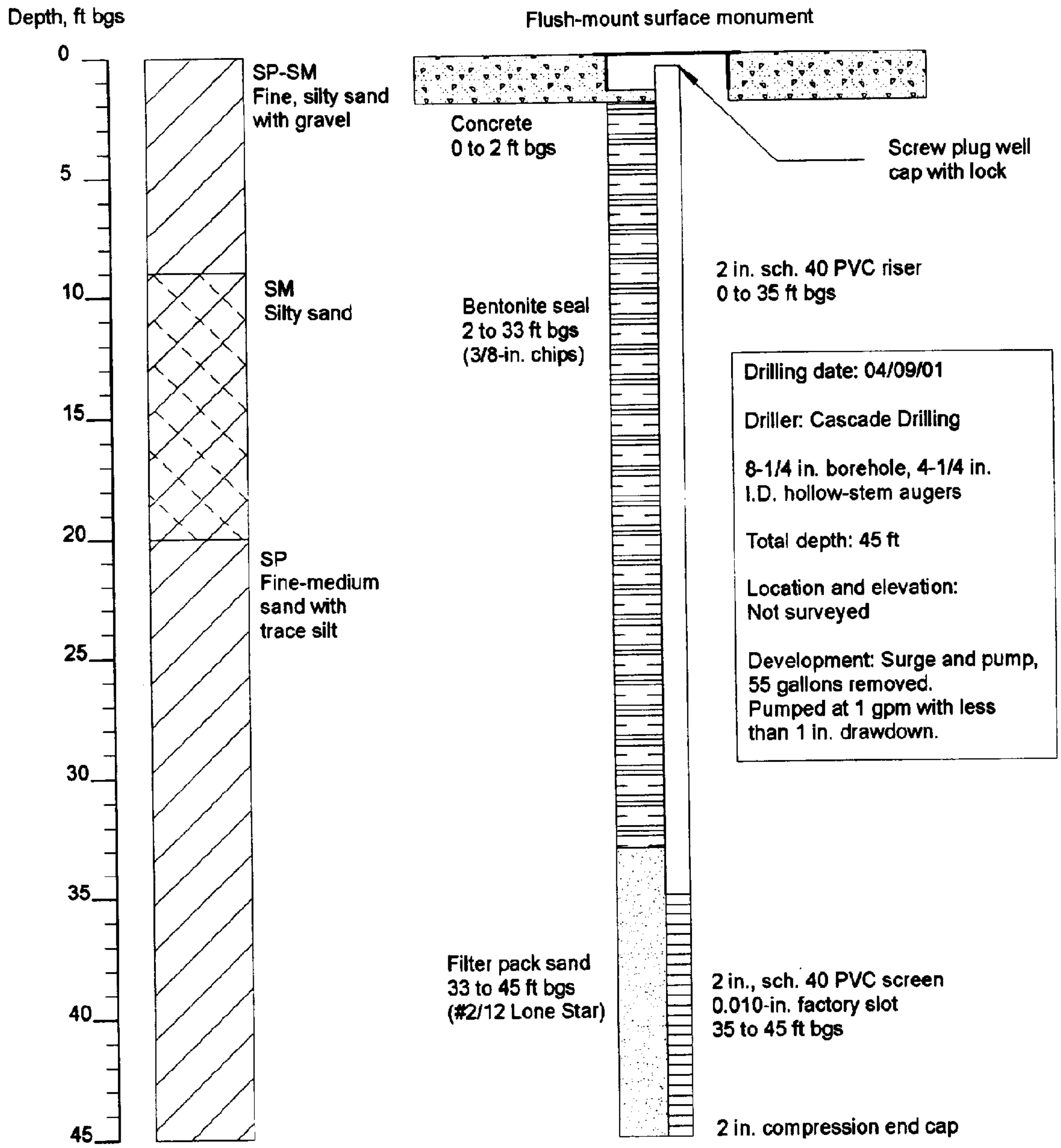
DEPTH	SAMPLE TYPE/NO. & DEPTH	BLOW COUNT PER 6 IN.	PERCENT RECOVERY	NOTES: (PRODUCT, ODOR, OVA READING, ETC.)	USCS LOG	STRATIGRAPHIC DESCRIPTION
				PID ppmv		13 D sounded at 45.2 ft bgs (to be replaced)
10'	SS 10' to 11.5' NA	3 3 3	100%	0.0	SM	Silty fine sand, black
15'	SS 15' to 16.5' NA	8 7 8	100%	0.1	SP	Fine to medium sand, black w/ red/white flecks; saturated
20'	SS 20' to 21.5' NA	7 11 15	100%	0.5	SP	Same as above (SAA)
25'	SS 25' to 26.5' NA	11 12 14	90%	6.3	SP	SAA
30'	SS 30' to 31.5' NA	10 15 19	50%	1.2	SP	SAA; slightly coarser
35'	SS 35' to 36.5' NA	3 8 12	30%	0.5	SP	SAA
40'	SS 40' to 41.5'	11 11	0			No recovery

SAMPLE TYPES
SS=SPLIT SPOON, ST=SHELBY TUBE
R= ROCK CORE, O=OTHER

KCSlip4 43982

DEPTH	SAMPLE TYPE/NO. & DEPTH	BLOW COUNT PER 6 IN.	PERCENT RECOVERY	NOTES: (PRODUCT, ODOR, OVA READING, ETC.)	USCS LOG	STRATIGRAPHIC DESCRIPTION
	NA	17				
45'	SS	5	100%	2.1	SP/SM	SAA; grading finer to SM from 46' to 46.5'
	45' to 46.5'	11				
	NA	15				At 45' depth at 0805
						Set 10 slot screen 35' to 45'
						Lonestar 2/12 sand 33' to 45'
						Grout from 2' to 33'
						Concrete from 0 to 2'

SAMPLE TYPES
SS=SPLIT SPOON, ST=SHELBY TUBE
R= ROCK CORE, O=OTHER



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REVISION NO.: 0	DATE: 04/24/01	ACAD FILE: EMF-WF-25.SKF

Monitoring Well EMF-WF-25

DRAWN: CJE	CLIENT: Boeing	PROJECT NO.: 1214-111
CHECKED: TJM	LOCATION: EMF Site West side Boeing Field	FIGURE: -

Project Performance CORPORATION

GEOLOGIC BORING LOG

PROJECT: Boeing EMF/West Boeing Field	**JOB NO.:** 1214-111	**SHEET 1 Of 3**	**BORING NO.:** EMF-WF-25
PROJECT LOCATION: West side of Boeing Field	**BORING LOCATION:**		**TOTAL DEPTH:** 45 ft
		BEGUN: 4/9/01	
DRILL CONTRACTOR: Cascade	**GEOLOGIST:** TJM	**FINISHED:** 4/9/01	
DRILL RIG:	**DRILLER:** Brian	**GROUND ELEV.:**	
HOLE SIZE: 8-1/4 in. (4-1/4 in. I.D. auger)	**WEATHER:**	**GROUND WATER (DEPTH/ELEV.):** Approximately 10 ft bgs	
DRILLING METHOD: Hollow-stem auger	**DRILLING FLUID/SOURCE:** N/A	**TOP OF ROCK (DEPTH/ELEV.):**	
SAMPLER TYPE: Dames & Moore split spoon		**HAMMER WEIGHT:** 140 lb	
SAMPLER LENGTH AND DIAM.: 12-in x 2-1/2 in. diameter		**HAMMER FALL:** 18 in.	

DEPTH	SAMPLE TYPE/DPETH/ NUMBER	BLOW COUNT PER 6 IN.	PERCENT RECOVERY	NOTES: (PRODUCT, ODOR, OVA READING, ETC.)	USCS LOG	STRATIGRAPHIC DESCRIPTION
				0 to 5 ft hand dug to clear Utilities		4 inches asphalt paving.
1 --					SP-SM	Fill, brown silty sand with gravel.
2 --						
3 --						
4 --						
5 --						
6 --						
7 --						
8 --						
9 --	SS/	3			SM	Brown silty sand, ¼-inch iron fine
10 --	9.0-10.5	3				oxide rust layers. 50% silt, 50%
	N/A	4				sand.

SAMPLE TYPES
SS=SPLIT SPOON, ST=SHELBY TUBE
R= ROCK CORE, O=OTHER

Project Performance Corporation

Boring: EMF-WF-25

Geologic Boring Log

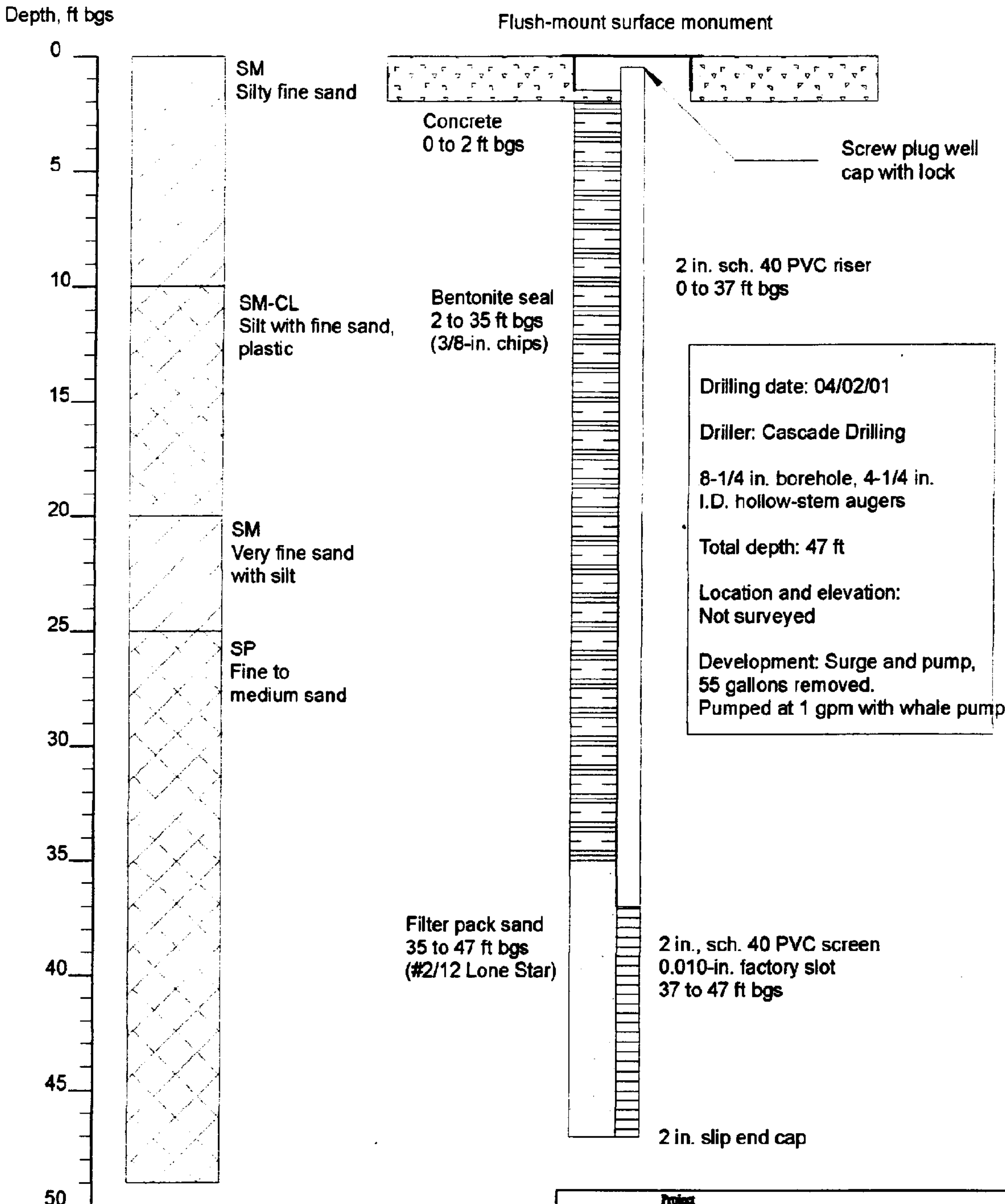
DEPTH	SAMPLE TYPE/DPETH/ NUMBER	BLOW COUNT PER 6 IN.	PERCENT RECOVERY	NOTES: (PRODUCT, ODOR, OVA READING, ETC.)	USCS LOG	STRATIGRAPHIC DESCRIPTION
11 --						
12 --						
13 --						
14 --						
15 --	SS/ 15.0-16.5 N/A	7 15 15			SM	Brown silt, changes to dark grey at 15.5 ft.
16 --						
17 --						
18 --						
19 --						
20 --	SS/ 20.0-21.5 N/A	5 7 8			SP	Saturated, black medium sand With red/white grains; trace silt (less than 5%), 40% fine sand, 50% medium sand.
21 --						
22 --						
23 --						
24 --						
25 --	SS/ 25.0-26.5/ N/A	7 15 9			SP	Same as above.
26 --						
27 --						
28 --						
29 --						
30 --						

SAMPLE TYPES
SS=SPLIT SPOON, ST=SHELBY TUBE
R= ROCK CORE, O=OTHER

Boring: EMF-WF-25

DEPTH	SAMPLE TYPE/DPETH/ NUMBER	BLOW COUNT PER 6 IN.	PERCENT RECOVERY	NOTES: (PRODUCT, ODOR, OVA READING, ETC.)	USCS LOG	STRATIGRAPHIC DESCRIPTION
31 --	SS/ 30.0-31.5/ N/A	6 12 20	95%		SP	Same as above
32 --						
33 --						
34 --						
35 --						
36 --	SS/ 35.0-36.5/ N/A	4 12 20	100%		SP	Same as above
37 --						
38 --						
39 --						
40 --						
41 --	SS/ 40.0-41.5/ N/A	6 9 11	80%		SP	Same as above
42 --						
43 --						
44 --						
45 --						
46 --	SS/ 45.0-46.5/ N/A	7 10 17	100%		SP	Same as above, slightly finer than above.
47 --						

SAMPLE TYPES
SS=SPLIT SPOON, ST=SHELBY TUBE
R= ROCK CORE, O=OTHER



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REVISION NO.: 0	DATE: 04/24/01	ACAD FILE: EMF-WF-26.SKF

Monitoring Well EMF-WF-26

DRAWN: CJE	CLIENT: Boeing	PROJECT NO.: 1214-111
	LOCATION:	
CHECKED: TJM	EMF Site West side Boeing Field	FIGURE: -

KCSlip4 43988

SEA410518

Project Performance Corporation

GEOLOGIC BORING LOG

PROJECT: Boeing EMF/West Boeing Field	**JOB NO.:** 1214-111	SHEET 1 Of 3	**BORING NO.:** EMF-WF-26
PROJECT LOCATION: West side of Boeing Field	**BORING LOCATION:**		**TOTAL DEPTH:** 49 ft
		BEGUN:	
DRILL CONTRACTOR: Cascade	**GEOLOGIST:** TJM	**FINISHED:**	
DRILL RIG:	**DRILLER:** Brian	**GROUND ELEV.:**	
HOLE SIZE: 8-1/4 in. (4-1/4 in. I.D. auger)	**WEATHER:** Rain	**GROUND WATER (DEPTH/ELEV.):** Approximately 10 ft bgs	
DRILLING METHOD: Hollow-stem auger	**DRILLING FLUID/SOURCE:** N/A	**TOP OF ROCK (DEPTH/ELEV.):**	
SAMPLER TYPE: Dames & Moore split spoon		**HAMMER WEIGHT:** 140	
SAMPLER LENGTH AND DIAM.: 12-in. x 2-1/2 in. diameter		**HAMMER FALL:** 18 in.	

DEPTH	SAMPLE TYPE/DPETH/ NUMBER	BLOW COUNT PER 6 IN.	PERCENT RECOVERY	NOTES: (PRODUCT, ODOR, OVA READING, ETC.)	USCS LOG	STRATIGRAPHIC DESCRIPTION
1 --				0 to 5 ft hand dug to clear Utilities	SM	Brown silty fine sand
2 --						
3 --						
4 --						
5 --						
6 --						
7 --						
8 --						
9 --						
10 --						

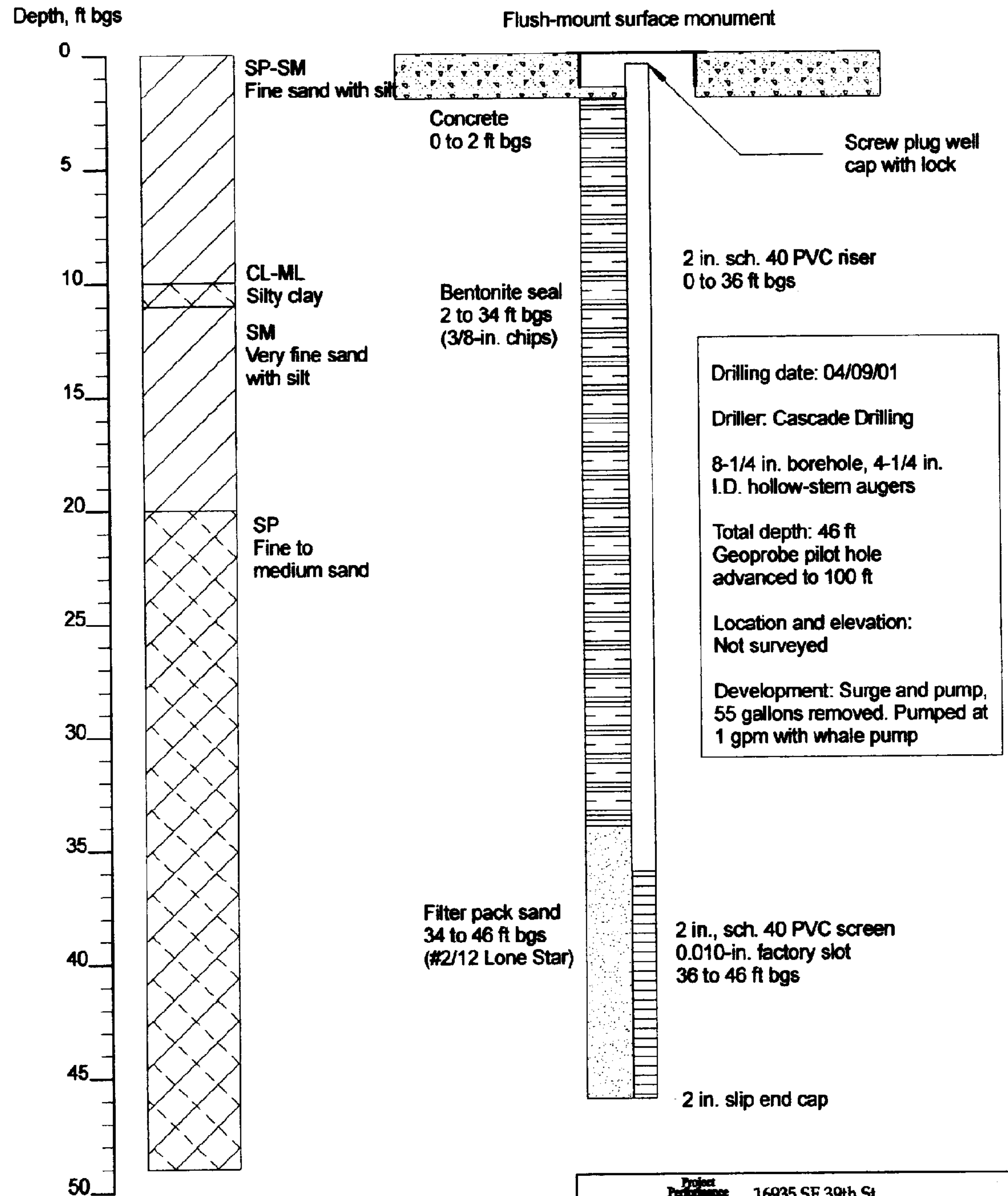
SAMPLE TYPES
SS=SPLIT SPOON, ST=SHELBY TUBE
R= ROCK CORE, O=OTHER

DEPTH	SAMPLE TYPE/DEPTH/ NUMBER	BLOW COUNT PER 6 IN.	PERCENT RECOVERY	NOTES: (PRODUCT, ODOR, OVA READING, ETC.)	USCS LOG	STRATIGRAPHIC DESCRIPTION
11 --	SS/ 10.0-11.5/ N/A	6 7 7	100%		SM-CL	Silt with fine sand, plastic, wet. Top half brown, bottom half grey
12 --						
13 --						
14 --						
15 --	SS/ 15.0-16.5 N/A	7 7 7	80%		SM-CL	Same as above, all grey
16 --						
17 --						
18 --						
19 --						
20 --	SS/ 20.0-21.5 N/A	8 14 18	80%		SM	Very fine sand with silt, grey
21 --						
22 --						
23 --						
24 --						
25 --	SS/ 25.0-26.5/ GSB25	12 15 18	70%	Sample collected for grain Size analysis	SP	Fine to medium sand, black with Red/white grains.
26 --						
27 --						
28 --						
29 --						
30 --						

SAMPLE TYPES
SS=SPLIT SPOON, ST=SHELBY TUBE
R= ROCK CORE, O=OTHER

DEPTH	SAMPLE TYPE/DPETH/ NUMBER	BLOW COUNT PER 6 IN.	PERCENT RECOVERY	NOTES: (PRODUCT, ODOR, OVA READING, ETC.)	USCS LOG	STRATIGRAPHIC DESCRIPTION
31	SS/ 30.0-31.5/ N/A	5 8 15	50%		SP	Same as above, some coarser sand, some ½-in. wood fragments.
32						
33						
34						
35				No split spoon sample collected, logged from Geoprobe sample.	SP	Same as above
36						
37						
38						
39						
40	SS/ 40.0-41.5/ N/A	5 7 14	70%		SP	Same as above
41						
42						
43						
44						
45	SS/ 45.0-46.5/ GSB45A	5 10 15	80%	Sample collected for grain Size analysis	SP	Same as above, grading slightly finer than above.
46						
47						
48						
49						

SAMPLE TYPES
SS=SPLIT SPOON, ST=SHELBY TUBE
R= ROCK CORE, O=OTHER



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REVISION NO.: 0	DATE: 04/30/01	ACAD FILE: EMF-WF-27.SKF

Monitoring Well EMF-WF-27

DRAWN: CJE	CLIENT: Boeing	PROJECT NO.: 1214-113
CHECKED: TJM	LOCATION: EMF Site West side Boeing Field	FIGURE: -

KCSlip4 43992

SEA410522

Project Performance CORPORATION

GEOLOGIC BORING LOG

PROJECT: Boeing EMF/West Boeing Field	**JOB NO.:** 1214-113	**SHEET** 1 Of 6	**BORING NO.:** EMF-WF-27
PROJECT LOCATION: West side of Boeing Field	**BORING LOCATION:**		**TOTAL DEPTH:** 100 ft
		BEGUN:	
DRILL CONTRACTOR: Cascade	**GEOLOGIST:** TJM	**FINISHED:**	
DRILL RIG: Geoprobe	**DRILLER:** Kasey Gabel	**GROUND ELEV.:**	
HOLE SIZE: 1-1/2 in.	**WEATHER:** Rain	**GROUND WATER (DEPTH/ELEV.):** Approximately 10 ft bgs	
DRILLING METHOD: Direct push	**DRILLING FLUID/SOURCE:** N/A	**TOP OF ROCK (DEPTH/ELEV.):**	
SAMPLER TYPE: Geoprobe		**HAMMER WEIGHT:** N/A	
SAMPLER LENGTH AND DIAM.: 22 in x 1-1/16 in. diameter		**HAMMER FALL:** N/A	

DEPTH	SAMPLE TYPE/DPETH/ NUMBER	BLOW COUNT PER 6 IN.	PERCENT RECOVERY	NOTES: (PRODUCT, ODOR, OVA READING, ETC.)	USCS LOG	STRATIGRAPHIC DESCRIPTION
1 --				0 to 5 ft hand dug to clear Utilities	SP-SM	Fine sand with silt,
2 --						
3 --						
4 --						
5 --						
6 --						
7 --						
8 --						
9 --						
10 --						

SAMPLE TYPES
SS=SPLIT SPOON, ST=SHELBY TUBE
R= ROCK CORE, O=OTHER

DEPTH	SAMPLE TYPE/DPETH/ NUMBER	BLOW COUNT PER 6 IN.	PERCENT RECOVERY	NOTES: (PRODUCT, ODOR, OVA READING, ETC.)	USCS LOG	STRATIGRAPHIC DESCRIPTION
	O/ 10.0-12.0/ N/A		100%		CL-ML	Tan/grey silty clay layer from 10 to 11 ft
11 --					SM	Silty sand with >20% fines
12 --						
13 --						
14 --						
15 --						
16 --						
17 --						
18 --						
19 --						
20 --	O/ 20.0-22.0 N/A		100%		SP	Fine to medium sand, black with red/white grains, <5% fines
21 --						
22 --						
23 --						
24 --						
25 --				Water sample collected 25 to 29 ft. Sample number WBF-C-25. PID = 0.6 ppmv.		
26 --						
27 --						
28 --						
29 --						
30 --						

SAMPLE TYPES
SS=SPLIT SPOON, ST=SHELBY TUBE
R= ROCK CORE, O=OTHER

DEPTH	SAMPLE TYPE/DPETH/ NUMBER	BLOW COUNT PER 6 IN.	PERCENT RECOVERY	NOTES: (PRODUCT, ODOR, OVA READING, ETC.)	USCS LOG	STRATIGRAPHIC DESCRIPTION
31 --	O/ 30.0-32.0/ N/A		100%		SP	Same as above with some coarse sand.
32 --						
33 --						
34 --						
35 --	O/ 35.0-37.0/ N/A		100%	Water sample collected 35 to 39 ft. Sample number WBF-C-35. PID = 216 ppmv.	SP	Same as above, but somewhat finer.
36 --						
37 --						
38 --						
39 --						
40 --	O/ 40.0-42.0/ N/A		100%		SP	Same as above; grading finer, but still fine to medium sand.
41 --						
42 --						
43 --						
44 --						
45 --	O/ 45.0-47.0/ N/A		50%	Water sample collected 45 to 49 ft. Sample number WBF-C-45. PID = 28.6 ppmv.	SP	Same as above; 1-in. silt layer (ML-CL) at 47 ft.
46 --						
47 --						
48 --						
49 --						
50 --						

SAMPLE TYPES
SS=SPLIT SPOON, ST=SHELBY TUBE
R= ROCK CORE, O=OTHER

DEPTH	SAMPLE TYPE/DPETH/ NUMBER	BLOW COUNT PER 6 IN.	PERCENT RECOVERY	NOTES: (PRODUCT, ODOR, OVA READING, ETC.)	USCS LOG	STRATIGRAPHIC DESCRIPTION
	O/ 50.0-52.0/				CL-ML	1-ft layer silty clay.
51 --	N/A				SM	1-ft layer dense silty sand, plastic, grey.
52 --						Very fine silty sand, silt >20%.
53 --						
54 --						
55 --	O/ 55.0-57.0/		95%	Water sample collected 55 to 59 ft. Sample number WBF-C-55. PID = 0 ppmv.	SM	6-in. layers silty fine sand, fine to medium sand, and silty clay.
56 --	N/A					
57 --						
58 --						
59 --						
60 --						
61 --						
62 --						
63 --						
64 --						
65 --	O/ 65.0-67.0/		20%		SM	Silty very fine sand, not plastic.
66 --	N/A					
67 --						
68 --						
69 --						
70 --						

SAMPLE TYPES
SS=SPLIT SPOON, ST=SHELBY TUBE
R= ROCK CORE, O=OTHER

DEPTH	SAMPLE TYPE/DPETH/ NUMBER	BLOW COUNT PER 6 IN.	PERCENT RECOVERY	NOTES: (PRODUCT, ODOR, OVA READING, ETC.)	USCS LOG	STRATIGRAPHIC DESCRIPTION
71 --						
72 --	O/ 72.0-74.0/ N/A		80%		SP-GW	Fine sand with gravel up to 3/8 in., black with white grains. some black 1/8-in. grains. 6-in. layer plastic silty clay from 73.5 to 74 ft.
73 --						
74 --						
75 --						
76 --						
77 --						
78 --						
79 --	O/ 79.0-81.0/ N/A		50%		SM	Silty very fine sand; no layering, may be heave into sampler.
80 --						
81 --						
82 --						
83 --						
84 --						
85 --						
86 --						
87 --						
88 --						
89 --						

SAMPLE TYPES
SS=SPLIT SPOON, ST=SHELBY TUBE
R= ROCK CORE, O=OTHER

Project Performance Corporation

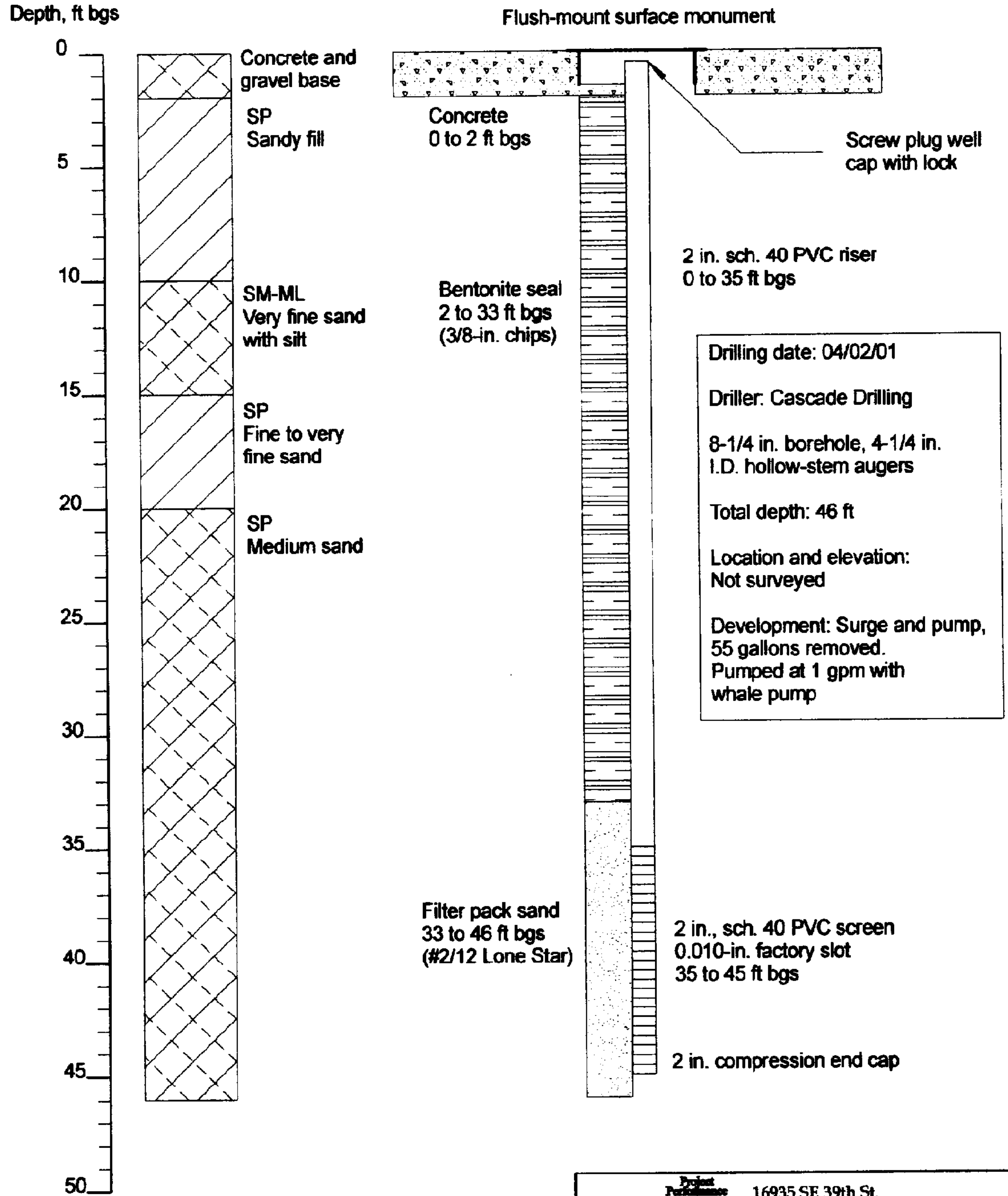
Geologic Boring Log

Boring: EMF-WF-27

DEPTH	SAMPLE TYPE/DPETH/ NUMBER	BLOW COUNT PER 6 IN.	PERCENT RECOVERY	NOTES: (PRODUCT, ODOR, OVA READING, ETC.)	USCS LOG	STRATIGRAPHIC DESCRIPTION
90 --	O/ 89.0-91.0/ N/A		25%		SP-SM	Fine to medium sand with >10% silt.
91 --						
92 --						
93 --						
94 --						
95 --						
96 --						
97 --						
98 --	O/ 98.0-100.0/ N/A				CL-ML	Grey, green silty clay, plastic, mottled layering.
99 --						
100 -						

SAMPLE TYPES
SS=SPLIT SPOON, ST=SHELBY TUBE
R= ROCK CORE, O=OTHER

KCSlip4 43998



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REVISION NO.: 0	DATE: 04/30/01	ACAD FILE: EMF-WF-28.SKF

Monitoring Well EMF-WF-28

DRAWN: CJE	CLIENT: Boeing	PROJECT NO.: 1214-113
CHECKED: TJM	LOCATION: EMF Site West side Boeing Field	FIGURE: –

KCSlip4 43999

Project Performance CORPORATION

GEOLOGIC BORING LOG

PROJECT: Boeing EMF/West Boeing Field	**JOB NO.:** 1214-113	**SHEET** 1 Of 3	**BORING NO.:** EMF-WF-28
PROJECT LOCATION: West side of Boeing Field	**BORING LOCATION:**		**TOTAL DEPTH:** 46 ft
		BEGUN:	
DRILL CONTRACTOR: Cascade	**GEOLOGIST:** TJM	**FINISHED:**	
DRILL RIG:	**DRILLER:** Brian Goss	**GROUND ELEV.:**	
HOLE SIZE: 8-1/4 in. (4-1/4 in. I.D. auger)	**WEATHER:** Rain	**GROUND WATER (DEPTH/ELEV.):** Approximately 10 ft bgs	
DRILLING METHOD: Hollow-stem auger	**DRILLING FLUID/SOURCE:** N/A	**TOP OF ROCK (DEPTH/ELEV.):**	
SAMPLER TYPE: Dames & Moore split spoon		**HAMMER WEIGHT:** 140	
SAMPLER LENGTH AND DIAM.: 12-in. x 2-1/2 in. diameter		**HAMMER FALL:** 18 in.	

DEPTH	SAMPLE TYPE/DEPTH/ NUMBER	BLOW COUNT PER 6 IN.	PERCENT RECOVERY	NOTES: (PRODUCT, ODOR, OVA READING, ETC.)	USCS LOG	STRATIGRAPHIC DESCRIPTION
1 --				0 to 5 ft hand dug to clear Utilities		9 in. concrete underlain by 18 in. gravel base.
2 --					SP	Sandy fill, dark brown
3 --						
4 --						
5 --						
6 --						
7 --						
8 --						
9 --						
10 --						

SAMPLE TYPES
SS=SPLIT SPOON, ST=SHELBY TUBE
R= ROCK CORE, O=OTHER

KCSlip4 44000

DEPTH	SAMPLE TYPE/DPETH/ NUMBER	BLOW COUNT PER 6 IN.	PERCENT RECOVERY	NOTES: (PRODUCT, ODOR, OVA READING, ETC.)	USCS LOG	STRATIGRAPHIC DESCRIPTION
11 --	SS/ 10.0-11.5/ GSD10	8 7 8	100%	Sample collected for grain Size analysis	SM-ML	Very fine sand with silt, >50% silt, plastic, grey.
12 --						
13 --						
14 --						
15 --						
16 --	SS/ 15.0-16.5 N/A	5 8 9			SP	Fine to very fine sand, ≈ 5% silt, black with red/white grains.
17 --						
18 --						
19 --						
20 --						
21 --	SS/ 20.0-21.5 GSD20	9 15 17	80%	Sample collected for grain Size analysis	SP	Medium sand with some coarse sand, black with red/white grains.
22 --						
23 --						
24 --						
25 --						
26 --	SS/ 25.0-26.5/ N/A	9 12 16	100%		SP	Same as above.
27 --						
28 --						
29 --						
30 --						

SAMPLE TYPES
SS=SPLIT SPOON, ST=SHELBY TUBE
R= ROCK CORE, O=OTHER

Project Performance Corporation | **Geologic Boring Log**

Boring: EMF-WF-28

DEPTH	SAMPLE TYPE/DPETH/ NUMBER	BLOW COUNT PER 6 IN.	PERCENT RECOVERY	NOTES: (PRODUCT, ODOR, OVA READING, ETC.)	USCS LOG	STRATIGRAPHIC DESCRIPTION
31 --	SS/ 30.0-31.5/ GSD30	5 8 15	60%	Sample collected for grain Size analysis	SP	Same as above
32 --						
33 --						
34 --						
35 --						
36 --	SS/ 35.0-36.5/ N/A				SP	Same as above
37 --						
38 --						
39 --						
40 --						
41 --	SS/ 40.0-41.5/ GSD40	5 5 15	80%	Sample collected for grain Size analysis	SP	Same as above, few 3/8 in. sharp edge gravels.
42 --						
43 --						
44 --						
45 --						
46 --	SS/ 45.0-46.5/ N/A	10 11 14	40%		SP	Same as above.

SAMPLE TYPES
SS=SPLIT SPOON, ST=SHELBY TUBE
R= ROCK CORE, O=OTHER

Project Performance CORPORATION

GEOLOGIC BORING LOG

PROJECT: Boeing EMF/West Boeing Field	**JOB NO.:** 1214-111	**SHEET 1** Of 24	**BORING NO.:** EMF-WF-29
PROJECT LOCATION: West side of Boeing Field	**BORING LOCATION:**		**TOTAL DEPTH:** 45 ft
		BEGUN: 4/2/01	
DRILL CONTRACTOR: Cascade	**GEOLOGIST:** TJM	**FINISHED:** 4/2/01	
DRILL RIG:	**DRILLER:** Brian Goss	**GROUND ELEV.:**	
HOLE SIZE: 8-1/4 in. (4-1/4 in. I.D. auger)	**WEATHER:**	**GROUND WATER (DEPTH/ELEV.):** Approximately 10 ft bgs	
DRILLING METHOD: Hollow-stem auger	**DRILLING FLUID/SOURCE:** N/A	**TOP OF ROCK (DEPTH/ELEV.):**	
SAMPLER TYPE: Dames & Moore split spoon		**HAMMER WEIGHT:** 140 lb	
SAMPLER LENGTH AND DIAM.: 12-in x 2-1/2 in. diameter		**HAMMER FALL:** 18 in.	

DEPTH	SAMPLE TYPE/DEPTH/ NUMBER	BLOW COUNT PER 6 IN.	PERCENT RECOVERY	NOTES: (PRODUCT, ODOR, OVA READING, ETC.)	USCS LOG	STRATIGRAPHIC DESCRIPTION
1				0 to 5 ft hand dug to clear Utilities		11 inches concrete.
					SP-SM	Fill, brown silty sand with gravel.
2						
3						
4						
5						
6						
7						
8						
9						
10	SS/ 9.0-10.5 N/A	6 6 7	100%	Grain size sample GSWF5-10	SM	Brown silty sand, 50% silt, 50% fine sand

SAMPLE TYPES
SS=SPLIT SPOON, ST=SHELBY TUBE
R= ROCK CORE, O=OTHER

KCSlip4 44003

SEA410533

DEPTH	SAMPLE TYPE/DPETH/ NUMBER	BLOW COUNT PER 6 IN.	PERCENT RECOVERY	NOTES: (PRODUCT, ODOR, OVA READING, ETC.)	USCS LOG	STRATIGRAPHIC DESCRIPTION
11 --						
12 --						
13 --						
14 --						
15 --	SS/ 15.0-16.5 N/A	5 7 11	100%	Grain size sample GSWF5-15	SP	Saturated, black fine to medium sand, black with red/white grains trace silt (less than 5%)
16 --						
17 --						
18 --						
19 --						
20 --	SS/ 20.0-21.5 N/A	7 11 15	70%		SP	Same as above
21 --						
22 --						
23 --						
24 --						
25 --	SS/ 25.0-26.5/ N/A	8 18 23	80%		SP	Same as above, slightly more silt ~ 5 to 10% range
26 --						
27 --						
28 --						
29 --						
30 --						

SAMPLE TYPES
SS=SPLIT SPOON, ST=SHELBY TUBE
R= ROCK CORE, O=OTHER

Boring: EMF-WF-29

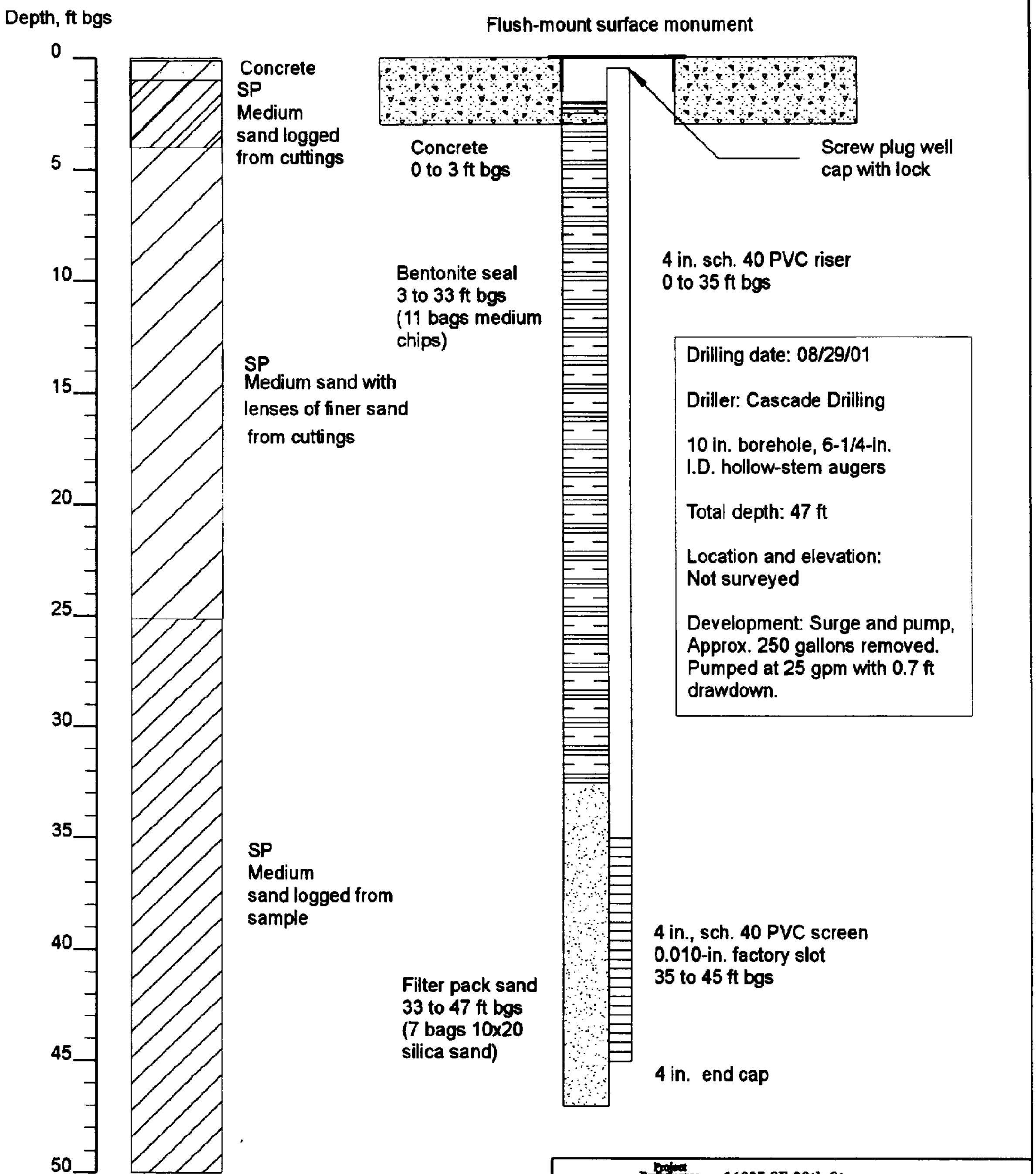
DEPTH	SAMPLE TYPE/DPETH/ NUMBER	BLOW COUNT PER 6 IN.	PERCENT RECOVERY	NOTES: (PRODUCT, ODOR, OVA READING, ETC.)	USCS LOG	STRATIGRAPHIC DESCRIPTION
31	SS/ 30.0-31.5/ N/A	3 4 12	80%		SP	Same as above, one ½ inch silt lense
32						
33						
34						
35	SS/ 35.0-36.5/ N/A	8 10 15	80%	Grain size sample GSWF5-35	SP	Same as above
36						
37						
38						
39						
40	SS/ 40.0-41.5/ N/A	12 15 17	80%		SP	Same as above, some ¼ to 3/8 Inch gravel, rounded ~ 1-5%
41						
42						
43						
44						
45	SS/ 45.0-46.5/ N/A	4 6 11	40%		SP	Same as above, no gravel
46						
47						
48						
49						
50						

SAMPLE TYPES
SS=SPLIT SPOON, ST=SHELBY TUBE
R= ROCK CORE, O=OTHER

Boring: EMF-WF-29

DEPTH	SAMPLE TYPE/DPETH/ NUMBER	BLOW COUNT PER 6 IN.	PERCENT RECOVERY	NOTES: (PRODUCT, ODOR, OVA READING, ETC.)	USCS LOG	STRATIGRAPHIC DESCRIPTION
51 --	SS/ 50.0-51.5/ N/A	3 4 12	20%		SP	Same as above, increasing silt (~ 5-10%)
52 --						
53 --						
54 --						
55 -- 56 --	SS/ 55.0-56.5/ N/A	7 8 14	30%		SP	Same as above

SAMPLE TYPES
SS=SPLIT SPOON, ST=SHELBY TUBE
R= ROCK CORE, O=OTHER



16935 SE 39th St.
Bellevue, WA 98008
(425) 643-4634 fax (425) 649-0643

REVISION NO.:	DATE:	ACAD FILE:
0	09/4/01	35.SKF

Monitoring Well WF 35

DRAWN:	CLIENT:	PROJECT NO.:
JJD	Boeing	1214-113
	LOCATION:	
CHECKED: TJM	EMF Site West Boeing Field	FIGURE: -

KCSlip4 44007

SEA410537

Project Performance Corporation

GEOLOGIC BORING LOG

PROJECT: EMF/west Boeing field	JOB NO.: 1214-113	SHEET 1 Of 1	BORING NO.: WF-35
PROJECT LOCATION: EMF, Boeing Field	BORING LOCATION:		TOTAL DEPTH: 47 ft
		BEGUN: 8/29/01 0715	
DRILL CONTRACTOR: Cascade	GEOLOGIST: JJD	FINISHED: 8/29/01 0940	
DRILL RIG:	DRILLER: Brian	GROUND ELEV.:	
HOLE SIZE: 61/4 ID auger, 10 in. hole	WEATHER: clear	GROUND WATER (DEPTH/ELEV.): 9.38 feet	
DRILLING METHOD: Hollow-stem auger	DRILLING FLUID/SOURCE: N/A	TOP OF ROCK (DEPTH/ELEV.):	
SAMPLER TYPE: SS		HAMMER WEIGHT:	
SAMPLER LENGTH AND DIAM.: 12" x 2"		HAMMER FALL:	

DEPTH	SAMPLE TYPE/DPETH/ NUMBER	BLOW COUNT PER 6 IN.	PERCENT RECOVERY	NOTES: (PRODUCT, ODOR, OVA READING, ETC.)	USCS LOG	STRATIGRAPHIC DESCRIPTION
1 --						Concrete
					SP	Med blackish brown sand w/ Red/white flecks; well graded
4 --					SP	Based on drill cuttings, SAA w/ Lenses of med to fine gray Sand w/ orange mottling (Fe); Cuttings saturated at ~17'
15--						
20--						
25--						
30--						Water added to control heave
	SS 30 - 31	25,50	100%	PID = 0.0	SP	Med black sand w/ red/white Flecks; well graded; wood bits
35--	SS 35 - 36	4,8,15	100%	PID = 0.0	SP	SAA small amount of wood
40--	SS 40 - 41	7,7,20	100%	PID = 0.0	SP	SAA
45--	SS 45 - 46	6,10,15	30%	PID = 0.0	SP	SAA; large piece of wood Debris caused low recovery
50-						Drilled to 50', heaved to 47'

Set screen at 45 ft.- 35 ft.; 10 slot
Filter pack is 10x20 silica sand from 47 ft. to 33 ft. – 7 bags
Grout is medium bentonite chips from 33 ft. to 3 ft. – 11 bags
Cement from 3 ft. to 0
Well is flush mount

SS = Split spoon

KCSlip4 44008

Appendix B --Particle-Size Analyses

REG Lab WMBE
Rosa Environmental & Geotechnical Laboratory, LLC

1001 SW Klickitat Way, Suite 107
Seattle, WA 98134
(206) 287-9122

April 16, 2001

Ms. Stephanie Lucas
Analytical Resources, Inc.
400 Ninth Avenue North
Seattle, WA 98109

ARI Project No.: CY61, REGL Project No.: 1000-309

Dear Ms. Lucas,

Two samples from the referenced project were received for grain size analysis on April 11, 2001. The results of the analysis are discussed on the attached narrative and summary table.

Please call me to discuss any questions, or comments you may have on the data or its presentation.

Best Regards,
Rosa Environmental & Geotechnical Laboratory, LLC.

Harold Benny

Harold Benny
Laboratory Manager

REG Lab WMBE
Rosa Environmental & Geotechnical Laboratory, LLC

1001 SW Klickitat Way, Suite 107
Seattle, WA 98134
(206) 287-9122

Client: Analytical Resources, Inc.	REGL Project No.: 1000-309
Client Project: CY61	Sample Batch No.: N/A

Case Narrative

1. Two samples were received on April 11, 2001 for grain size analysis.
2. The samples were analyzed for grain size analysis according to ASTM D-422.
3. There were no anomalies in the samples or methods on this project.

Released by: Sharon L. Davis Date: 4/13/01
Laboratory Lead

Approved by: Harold B. Date: 4/13/01
Laboratory Manager

1000-309

SUBCONTRACTOR ANALYSIS REQUEST
CUSTODY TRANSFER 04\10\01 **ARI Project: CY61**

Laboratory: REG Lab
Lab Contact: Harold Benny
Lab Address: 400 Ninth Ave N, Ste B
Seattle, WA 98109-5187
Phone: 206-389-6156
Fax:

ARI Client: Boeing Corporate SHEA
Project ID: 1214-111
ARI PMgr: Stephanie Lucas
Phone: (206) 340-2866 Ext 106
Fax: (206) 621-7523

Analytical Protocol: In-house

Requested Turn Around: **04/22/01**
Fax Results (Y/N): **Yes**

ARI Sample ID	Client Sample ID		Sampled	Matrix	Bottles	Analyses
01-5349-CY61A	GSA25	22792	4/ 9/01	Soil	1	Grain Size (Subc)
01-5350-CY61B	GSA40	22793	4/ 9/01	Soil	1	Grain Size (Subc)

Limits of Liability. *Subcontractor is expected to perform all requested services in accordance with appropriate methodology following Standard Operating Procedures that meet standards for the industry. The total liability of ARI, its officers, agents, employees, or sucessors, arising out of or in connection with the requested services, shall not exceed the negotiated amount for said services. The agreement by the Subcontractor to perform services requested by ARI releases ARI from any liability in excess thereof, not withstanding any provision to the contrary in any contract, purchase order or co-signed agreement between ARI and the Subcontractor.*

Carrier	Airbill		Date
Relinquished by Carrie McDayle	Company ARI	Date 4/11/01	Time
Received by Cambra Strawn	Company Rosa Env.	Date 4/11/01	Time

Carrier	Airbill		Date
Relinquished by	Company	Date	Time
Received by	Company	Date	Time

KCSlip4 44012

SEA410542

ROSA ENVIRONMENTAL AND GEOTECHNICAL LABORATORY, LLC

Analytical Resources Inc.
CY61

Percent Finer Than Indicated Size

Sieve Size (microns)	2"	1"	3/4"	1/2"	3/8"	#4	#10 (2000)	#20 (850)	#40 (425)	#60 (250)	#100 (150)	#200 (75)
GSA25	100.0	100.0	100.0	100.0	100.0	99.9	99.9	97.1	52.5	17.5	6.3	2.1
GSA40	100.0	100.0	100.0	100.0	100.0	100.0	100.0	97.8	60.5	21.2	9.7	4.0

1000-309

KCSlip4 44013

SEA410543

Analytical Resources Inc.
CY61

Percent Retained in Each Size Fraction

Sieve Size (microns)	>4750	4750-2000	2000-850	850-425	425-250	250-125	125-75	<75
GSA25	0.1	0.1	2.8	44.6	35.0	11.2	4.2	2.1
GSA40	0.0	0.0	2.2	37.3	39.2	11.5	5.7	4.0

Analytical Resources Inc.
CY61

Moisture Content

Sample Identification	Moisture Content (%)
GSA25	24.5
GSA40	26.1

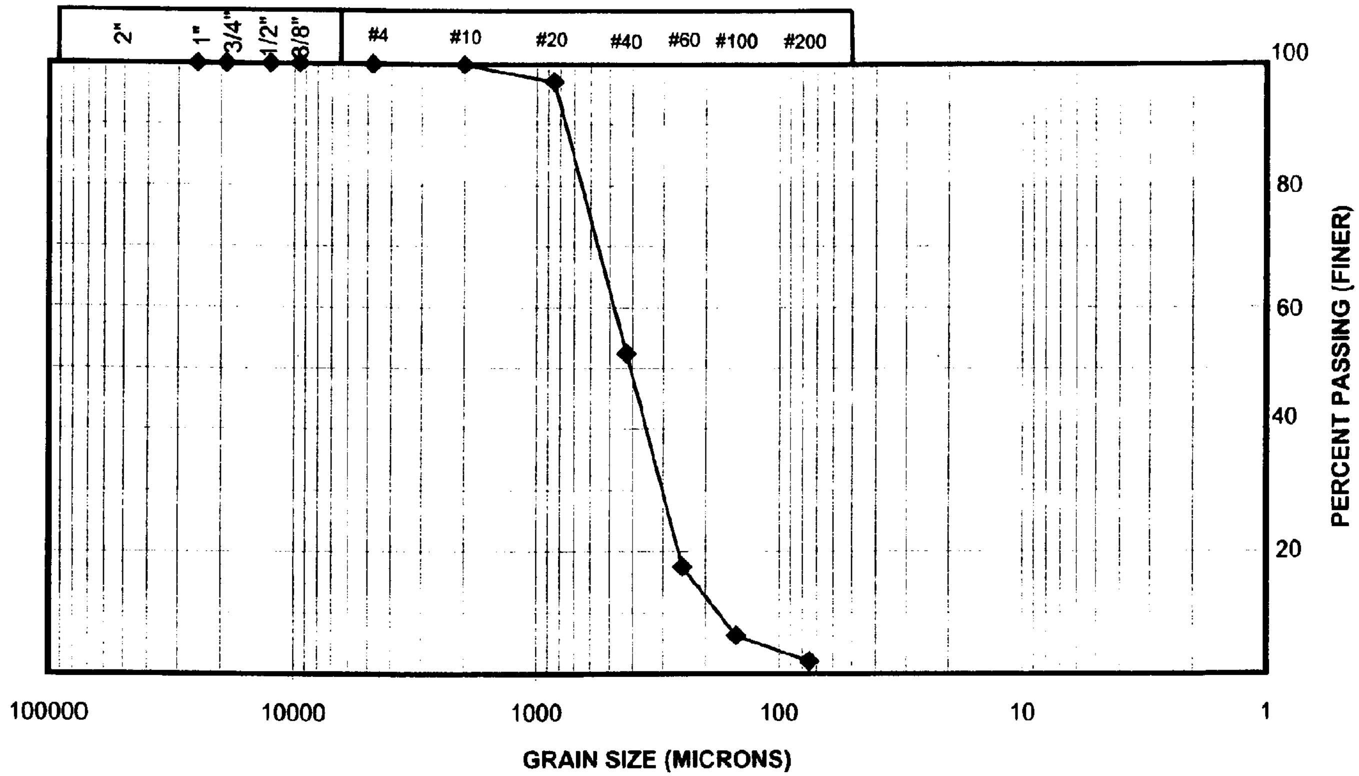
Tests conducted according to ASTM D-2216

1000-309

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: CY61
Sample No.: GSA25



1000-309

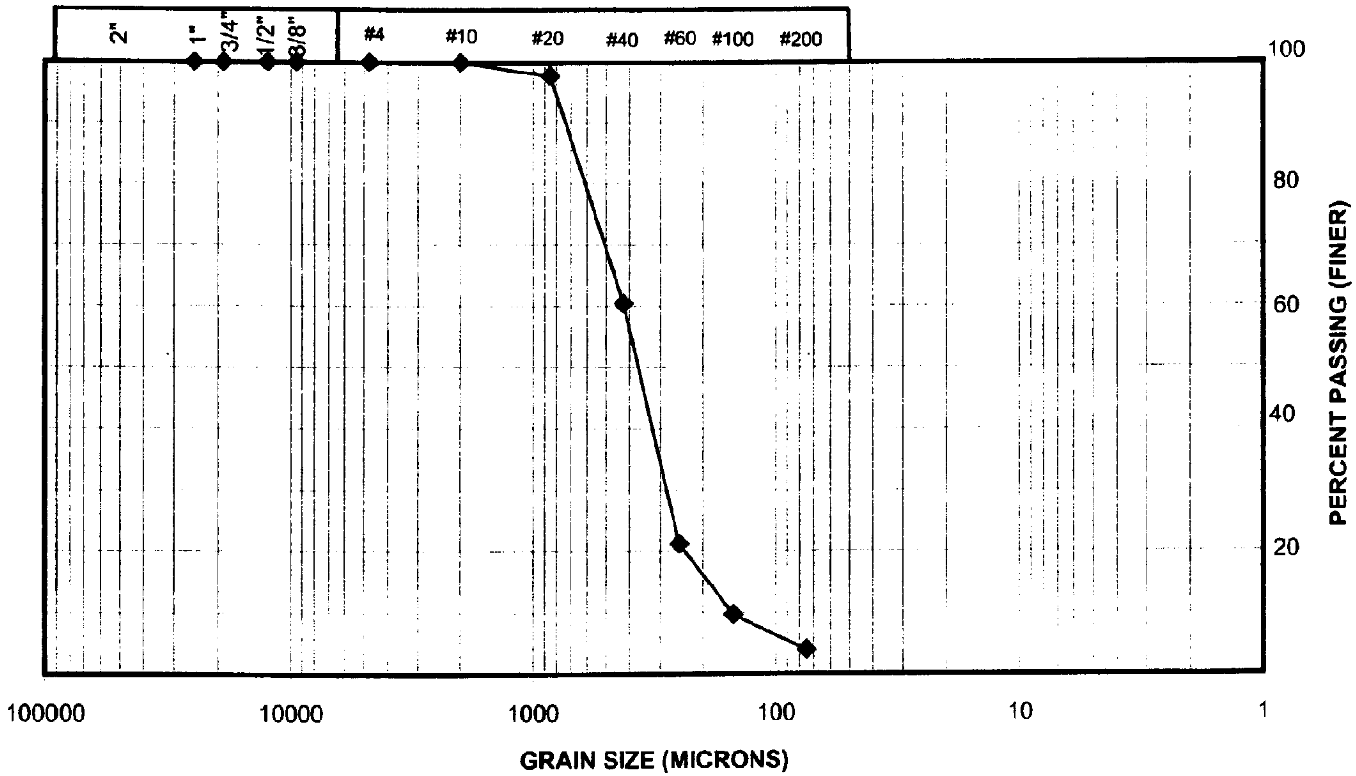
KCSlip4 44016

SEA410546

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: CY61
Sample No.: GSA40



1000-309

KCSlip4 44017

SEA410547

REG Lab WMBE
Rosa Environmental & Geotechnical Laboratory, LLC

1001 SW Klickitat Way, Suite 107
Seattle, WA 98134
(206) 287-9122

April 11, 2001

Mr. Tom McKeon
PPC
16935 SE 39th St.
Bellevue, WA 98008

Subject: Boeing EMF/WBF 1214-113, REGL Project No.: 1000-307

Dear Mr. McKeon,

Eleven samples from the referenced project were received for grain size analysis. Enclosed are the data tables, and graphs.

Please call me to discuss any questions, or comments you may have.

Best Regards,
Rosa Environmental & Geotechnical Laboratory, LLC.

Harold Benny
Laboratory Manager

KCSlip4 44018

REG Lab WMBE
Rosa Environmental & Geotechnical Laboratory, LLC

1001 SW Klickitat Way, Suite 107
Seattle, WA 98134
(206) 287-9122

Client: PPC	Project No.: 1000-307
Client Project: Boeing EMF/WBF 1214-113	Batch No.: 1000-307-01

Case Narrative

1. Eleven samples were received on April 5, 2001 for grain size analysis according to ASTM D-422.
2. A triplicate was run on one sample and the results can be found in the tables.
3. All samples appeared to be sands, except for GSD10 and GSWF5-10' these samples had a higher percentage of silt.
4. There were no anomalies in the samples or methods.

Released by: Sharon P. Davis Date: 4/11/2001
Title: Laboratory Lead

Approved by: [signature] Date: 4/11/2001
Title: Laboratory Manager

PPC
Boeing EMF/WBF 1214-113

Percent Retained in Each Size Fraction

Sieve Size (microns)	>4750	4750-2000	2000-850	850-425	425-250	250-125	125-75	<75
GSD20 A	0.0	0.4	11.8	55.0	26.2	3.8	1.6	1.1
GSD20 B	0.0	0.5	11.4	57.6	23.6	3.8	1.6	1.5
GSD20 C	0.0	0.4	11.5	55.0	25.9	3.7	1.6	1.9
GSD10	0.0	0.0	0.2	1.1	2.4	10.7	38.4	47.1
GSD30	0.1	0.5	13.0	43.7	26.0	9.7	3.8	3.1
GSB25	0.1	0.6	5.5	62.9	16.1	4.5	4.8	5.6
GSB45	0.0	0.4	4.7	58.3	24.7	5.6	3.3	2.9
GSWF5-55'	0.1	0.8	4.2	26.8	40.1	13.9	9.0	5.2
GSWF5-15'	0.0	0.0	2.9	51.9	34.5	7.3	1.7	1.7
GSD40	0.5	1.6	9.1	46.7	30.2	7.8	2.4	1.7
GSWF5-35'	0.0	0.1	2.1	44.4	41.3	7.7	2.5	1.9
GSD45	0.1	1.3	11.1	44.5	27.7	10.0	3.3	1.9
GSWF5-10'	0.0	0.0	0.0	1.5	5.2	3.8	31.2	58.2

PPC
Boeing EMF/WBF 1214-113

Moisture Content

Sample Identification	Moisture Content (%)
GSD20 A	16.6
GSD20 B	18.0
GSD20 C	23.0
GSD10	30.6
GSD30	18.9
GSB25	22.5
GSB45	21.0
GSWF5-55'	24.2
GSWF5-15'	21.0
GSD40	22.6
GSWF5-35'	24.8
GSD45	19.3
GSWF5-10'	28.5

Tests conducted according to ASTM D-2216

1000-307

PPC
Boeing EMF/WBF 1214-113

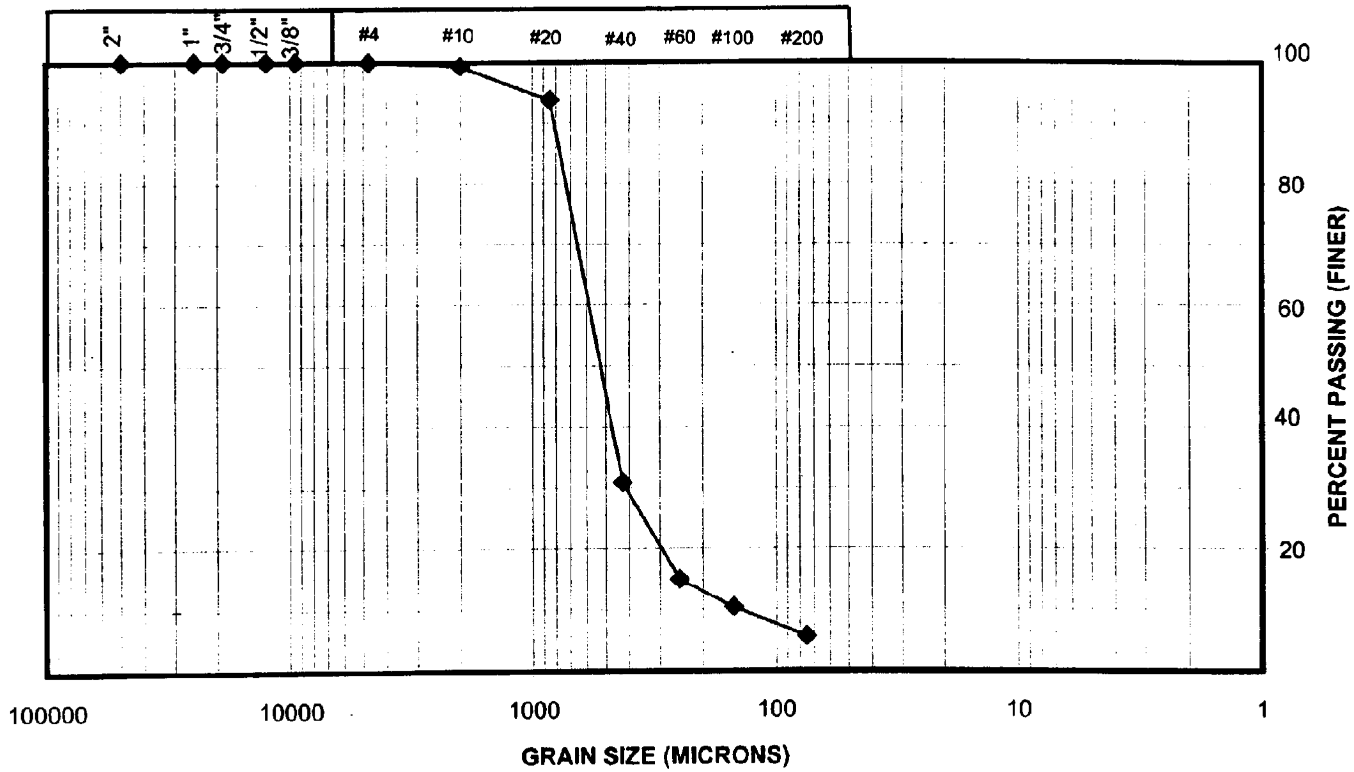
Percent Finer Than Indicated Size

Sieve Size (microns)	2"	1"	3/4"	1/2"	3/8"	#4	#10 (2000)	#20 (850)	#40 (425)	#60 (250)	#100 (150)	#200 (75)
GSD20 A	100.0	100.0	100.0	100.0	100.0	100.0	99.6	87.8	32.8	6.6	2.7	1.1
GSD20 B	100.0	100.0	100.0	100.0	100.0	100.0	99.5	88.1	30.5	6.9	3.1	1.5
GSD20 C	100.0	100.0	100.0	100.0	100.0	100.0	99.6	88.1	33.1	7.2	3.5	1.9
GSD10	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.7	98.6	96.2	85.5	47.1
GSD30	100.0	100.0	100.0	100.0	100.0	99.9	99.4	86.4	42.6	16.6	6.9	3.1
GSB25	100.0	100.0	100.0	100.0	100.0	99.9	99.3	93.9	30.9	14.9	10.4	5.6
GSB45	100.0	100.0	100.0	100.0	100.0	100.0	99.6	94.9	36.6	11.8	6.2	2.9
GSWF5-55'	100.0	100.0	100.0	100.0	100.0	99.9	99.1	94.9	68.2	28.1	14.2	5.2
GSWF5-15'	100.0	100.0	100.0	100.0	100.0	100.0	100.0	97.1	45.2	10.7	3.4	1.7
GSD40	100.0	100.0	100.0	100.0	100.0	99.5	97.9	88.8	42.2	12.0	4.1	1.7
GSWF5-35'	100.0	100.0	100.0	100.0	100.0	100.0	99.9	97.8	53.4	12.1	4.4	1.9
GSD45	100.0	100.0	100.0	100.0	100.0	99.9	98.6	87.5	43.0	15.3	5.3	1.9
GSWF5-10'	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	98.4	93.2	89.4	58.2

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: Boeing EMF/WBF 1214-113
Sample No.: GSB25



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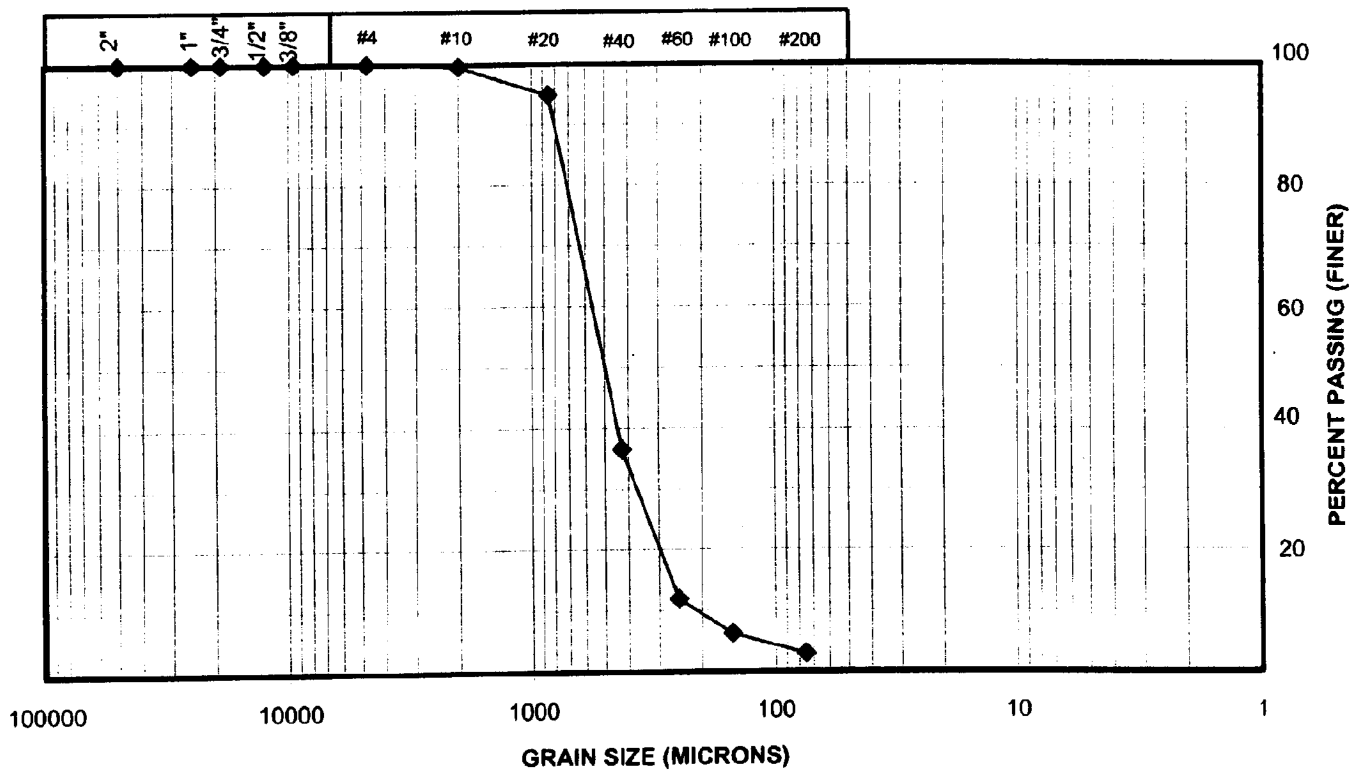
KCSlip4 44023

SEA410553

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: Boeing EMF/WBF 1214-113
Sample No.: GSB45



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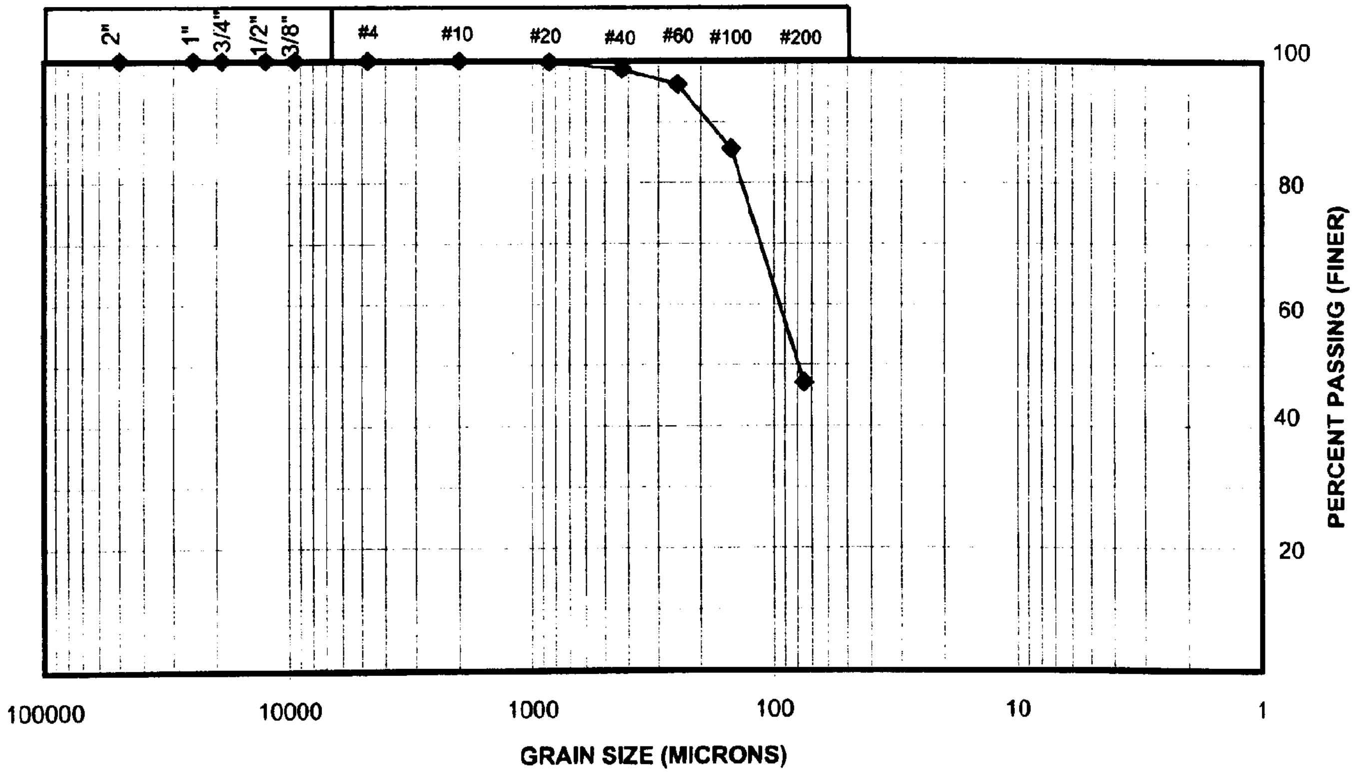
KCSlip4 44024

SEA410554

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: Boeing EMF/WBF 1214-113
Sample No.: GSD10



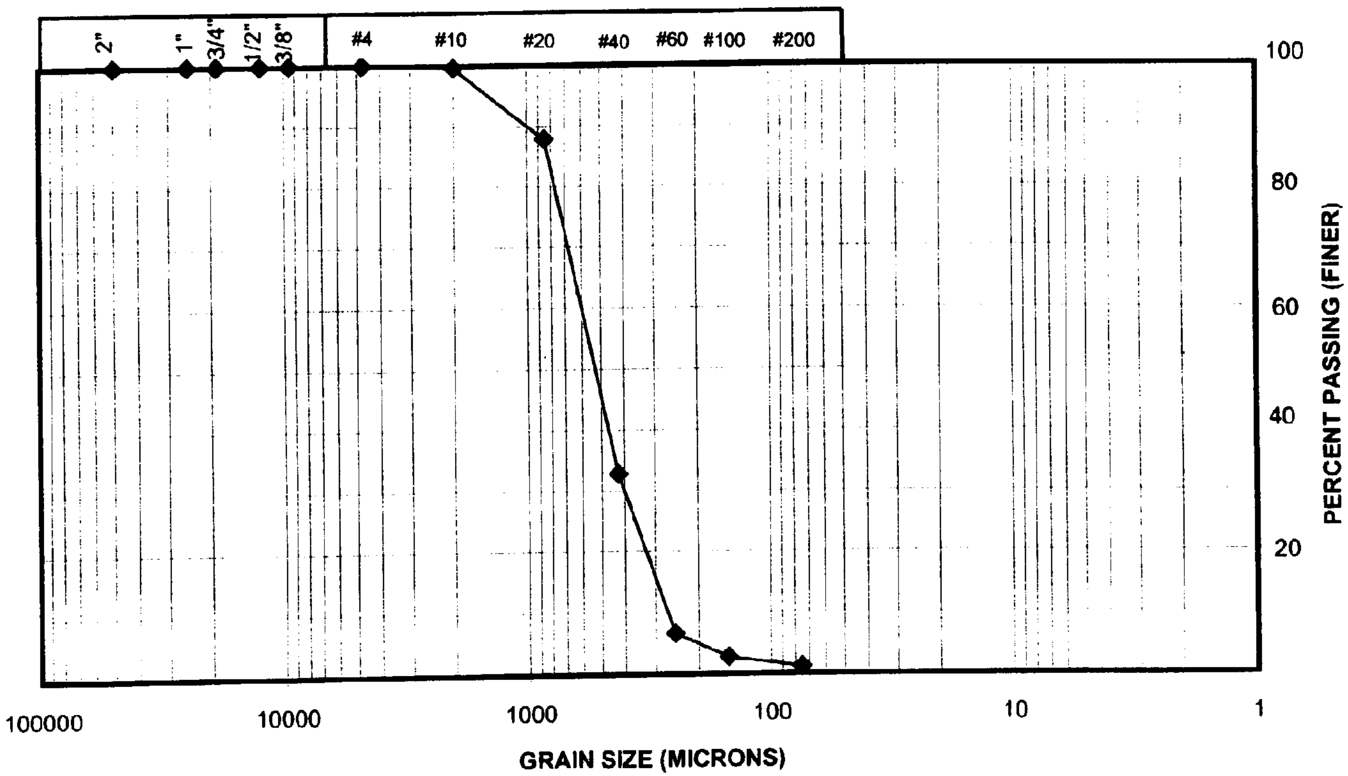
1000-307

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: Boeing EMF/WBF 1214-113

Sample No.: GSD20 A



1000-307

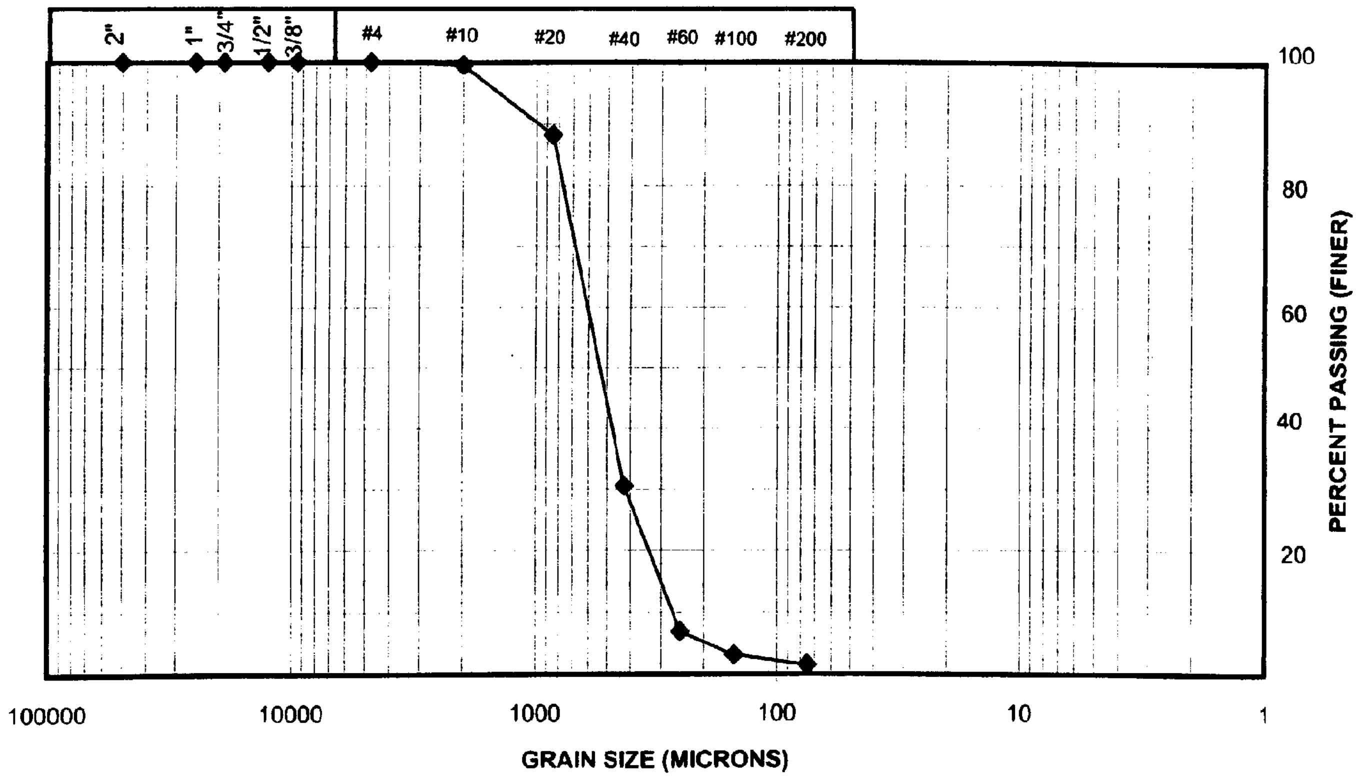
KCSlip4 44026

SEA410556

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: Boeing EMF/WBF 1214-113
Sample No.: GSD20 B



1000-307

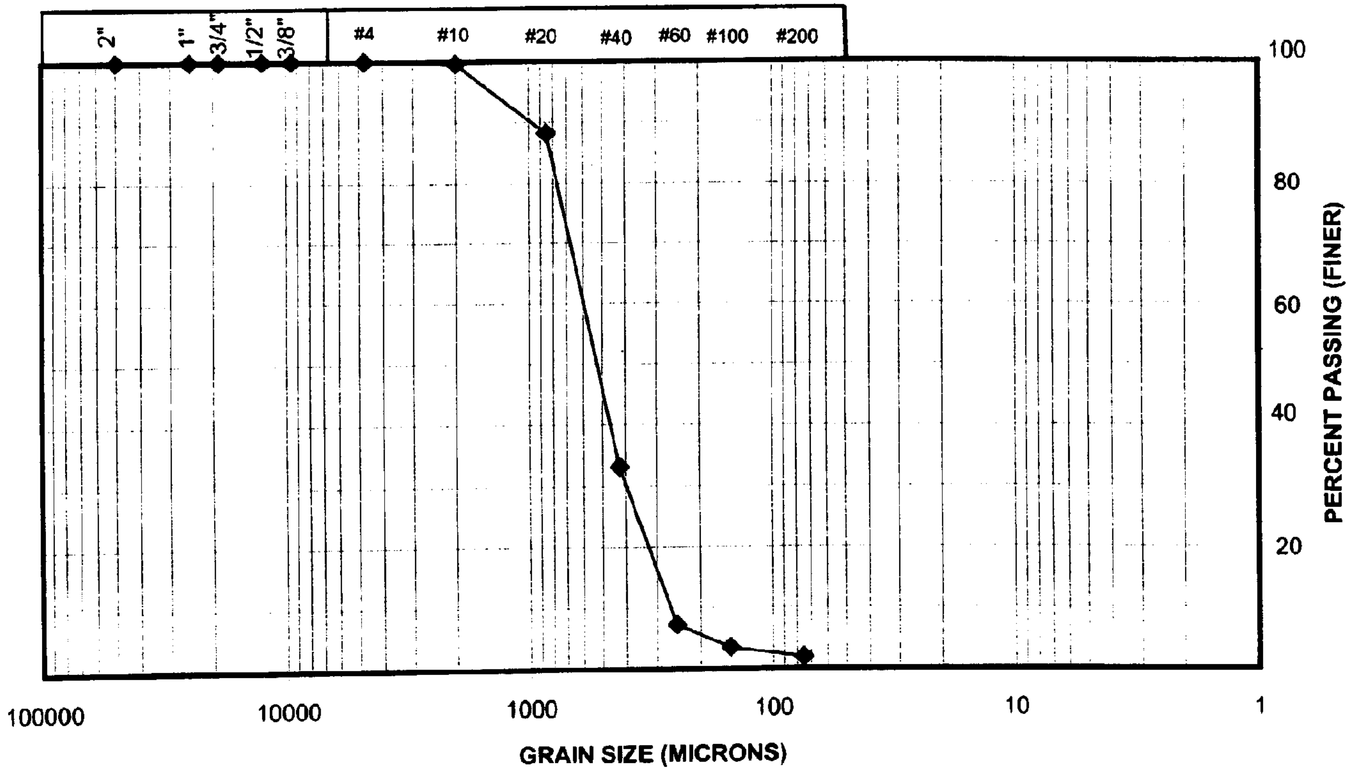
KCSlip4 44027

SEA410557

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: Boeing EMF/WBF 1214-113
Sample No.: GSD20 C



1000-307

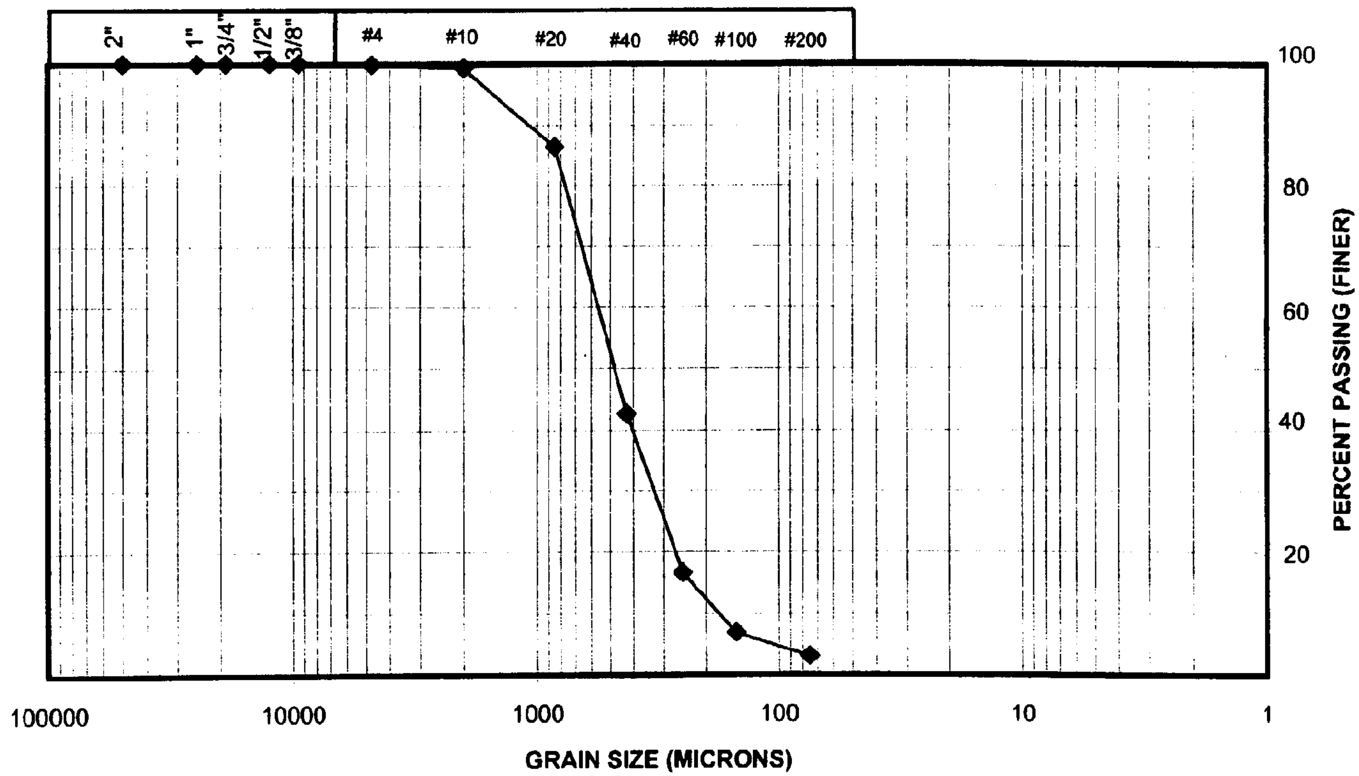
KCSlip4 44028

SEA410558

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: Boeing EMF/WBF 1214-113
Sample No.: GSD30

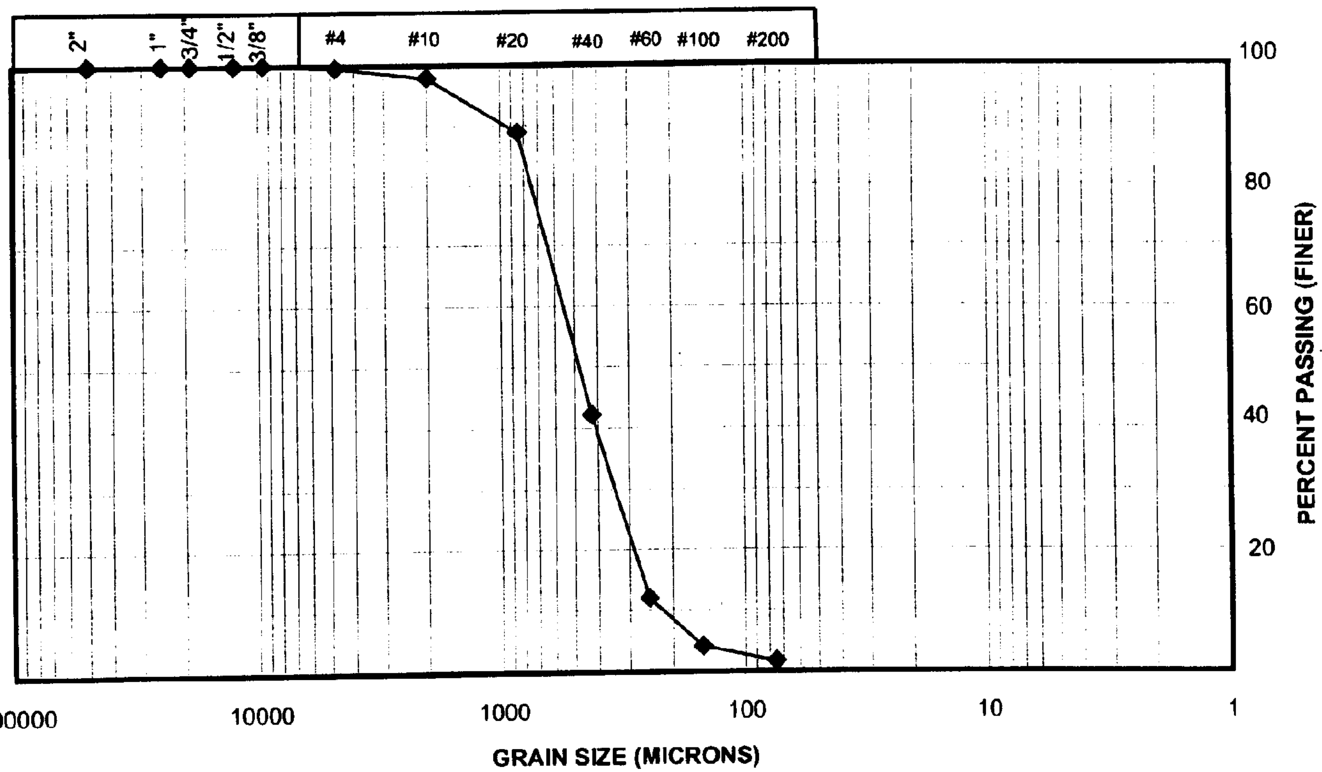


1000-307

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: Boeing EMF/WBF 1214-113
Sample No.: GSD40



1000-307

KCSlip4 44030

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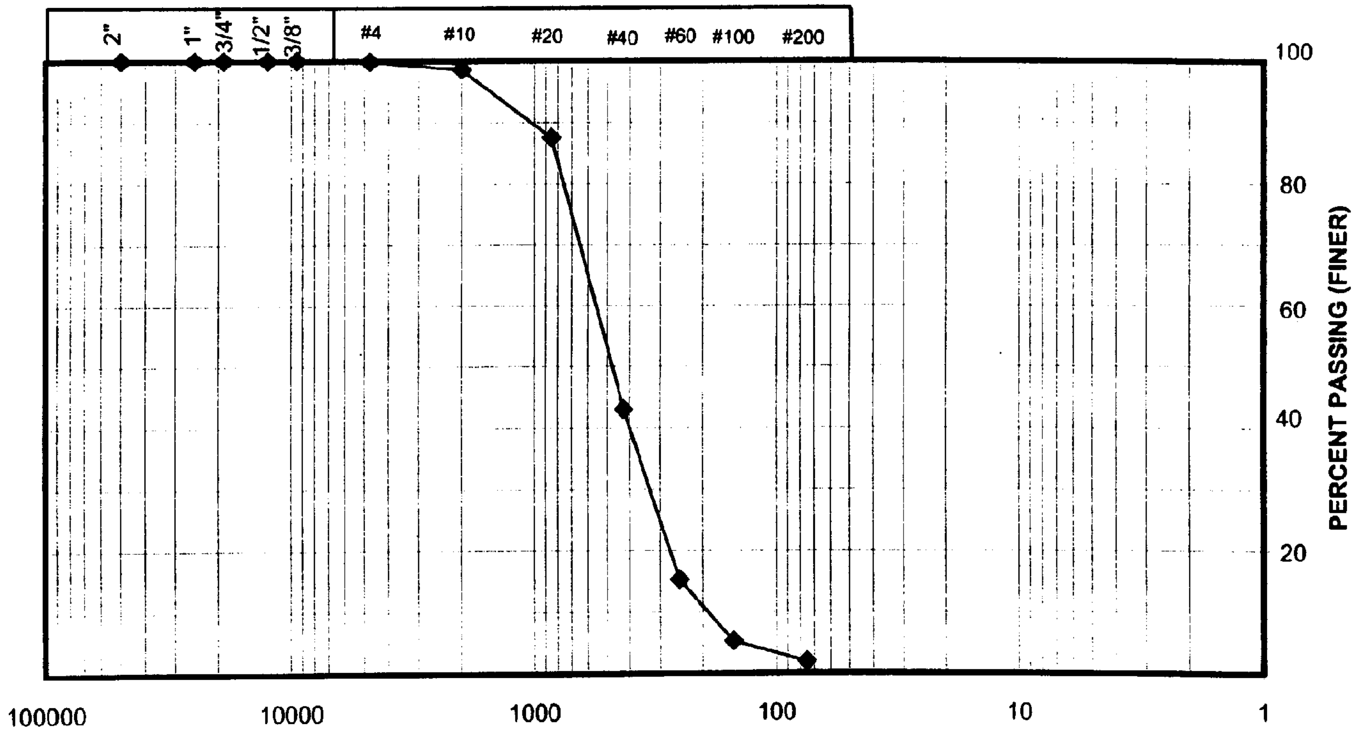
ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: Boeing EMF/WBF 1214-113
Sample No.: GSD45



1000-307

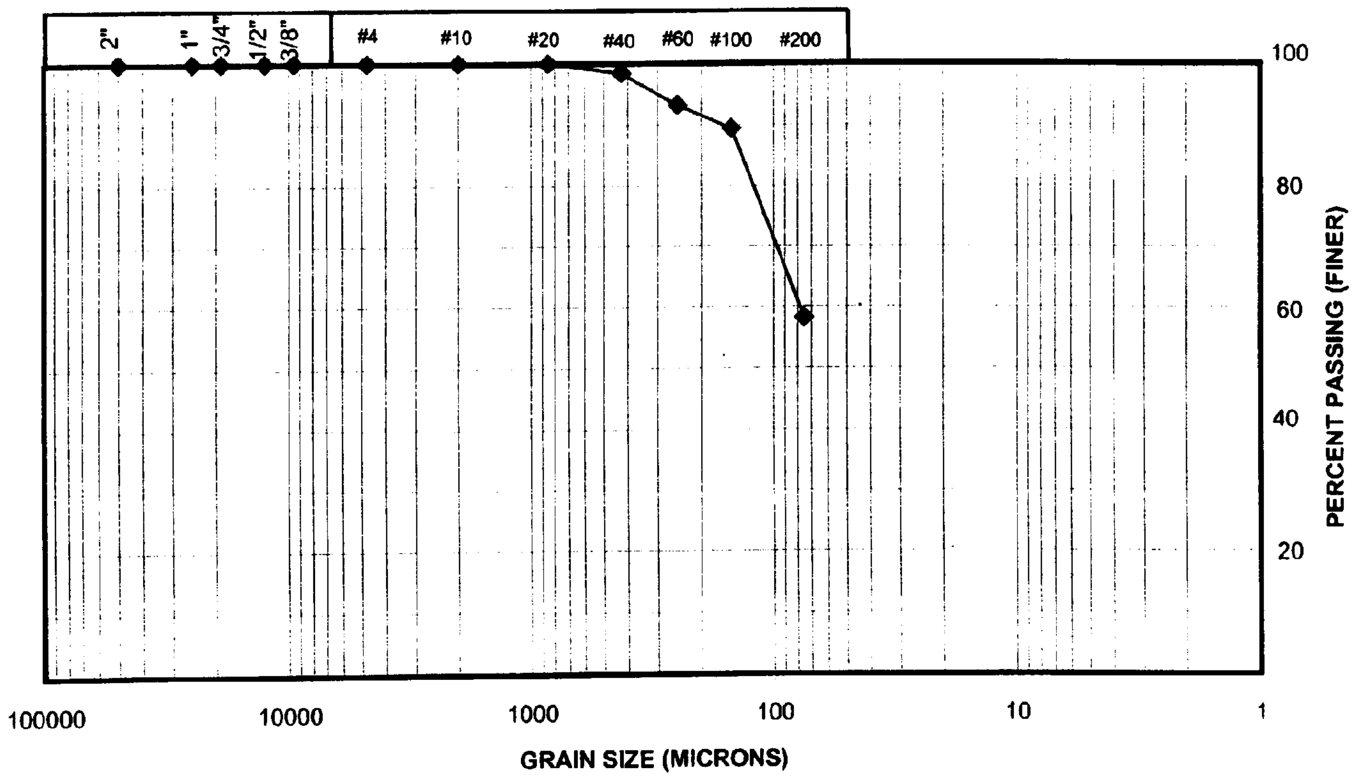
KCSlip4 44031

SEA410561

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: Boeing EMF/WBF 1214-113
Sample No.: GSWF5-10'



1000-307

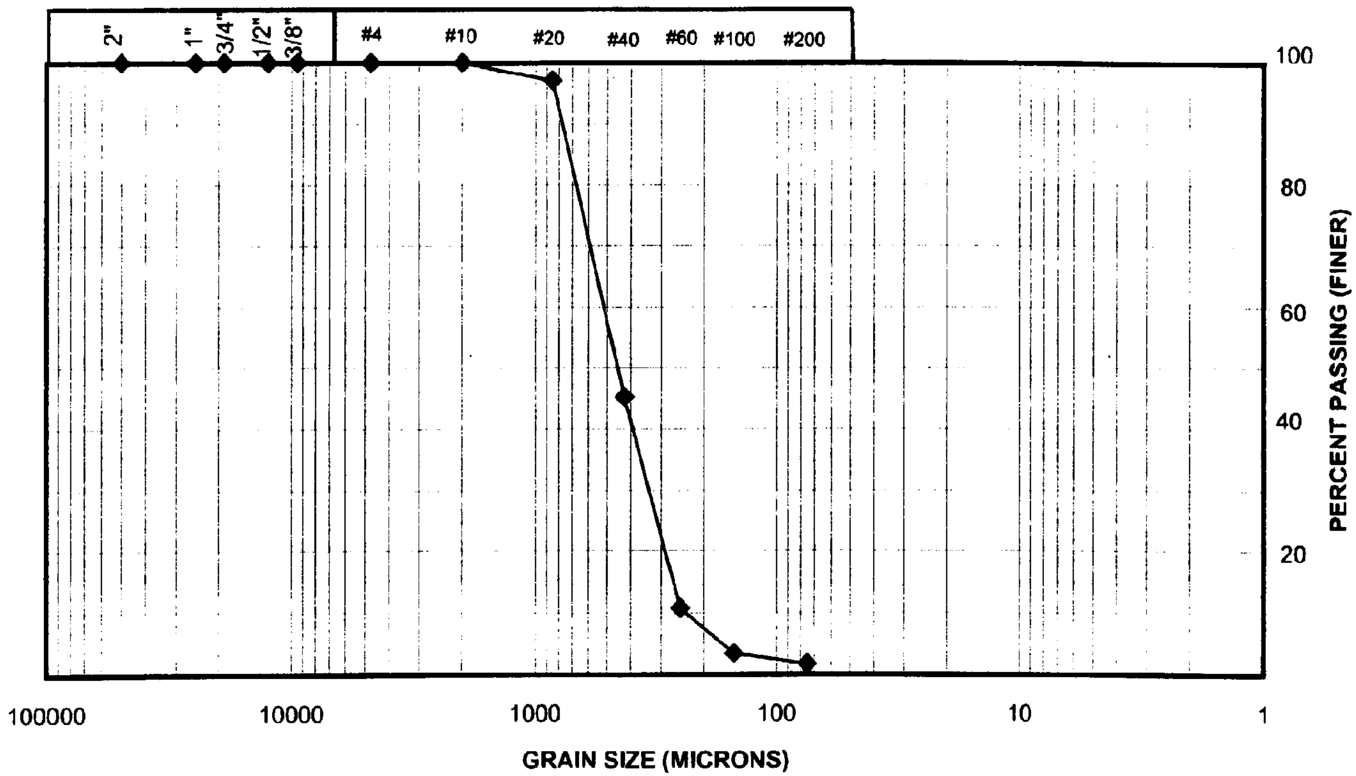
KCSlip4 44032

SEA410562

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: Boeing EMF/WBF 1214-113
Sample No.: GSWF5-15'



1000-307

KCSlip4 44033

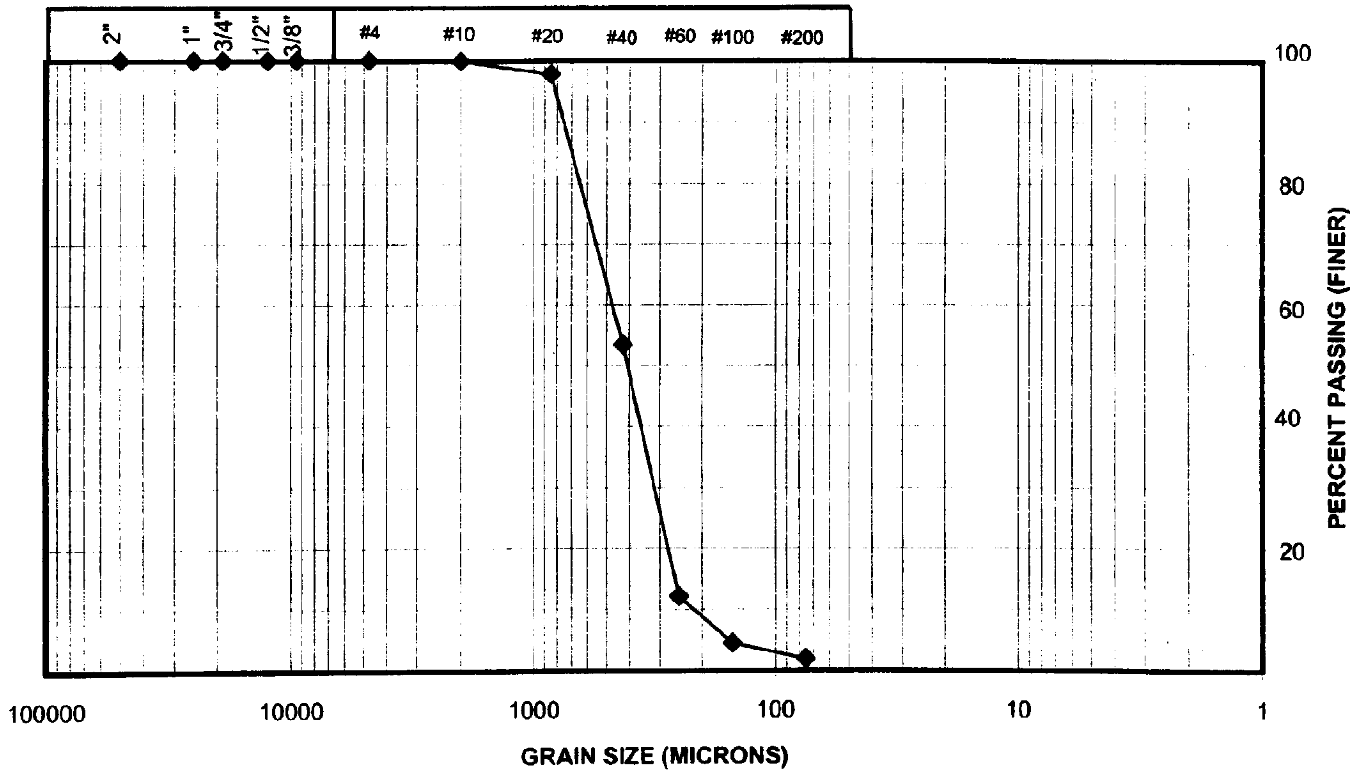
SEA410563

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: Boeing EMF/WBF 1214-113

Sample No.: GSWF5-35'



1000-307

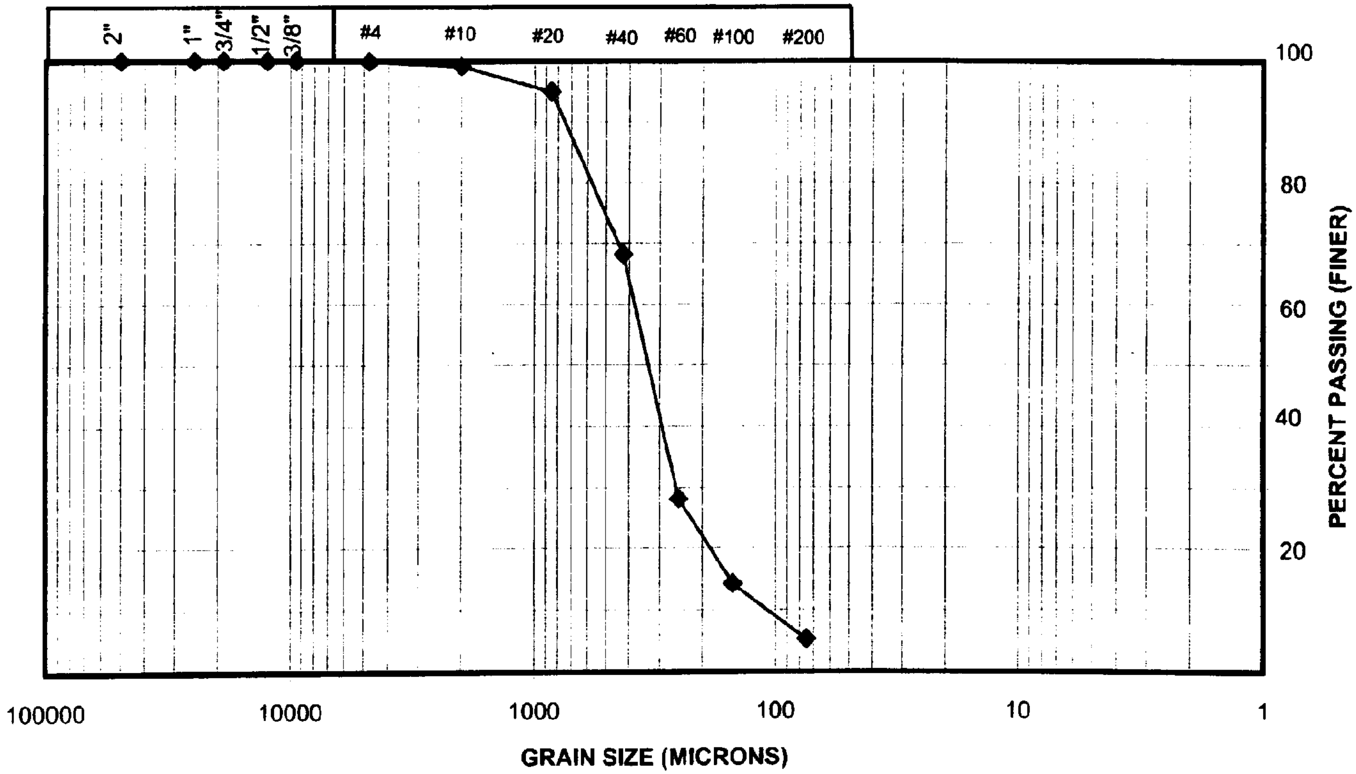
KCSlip4 44034

SEA410564

ROSA ENVIRONMENTAL & GEOTECHNICAL LABORATORY, LLC.

ASTM D-422 GRAIN SIZE DISTRIBUTION

Project: Boeing EMF/WBF 1214-113
Sample No.: GSWF5-55'

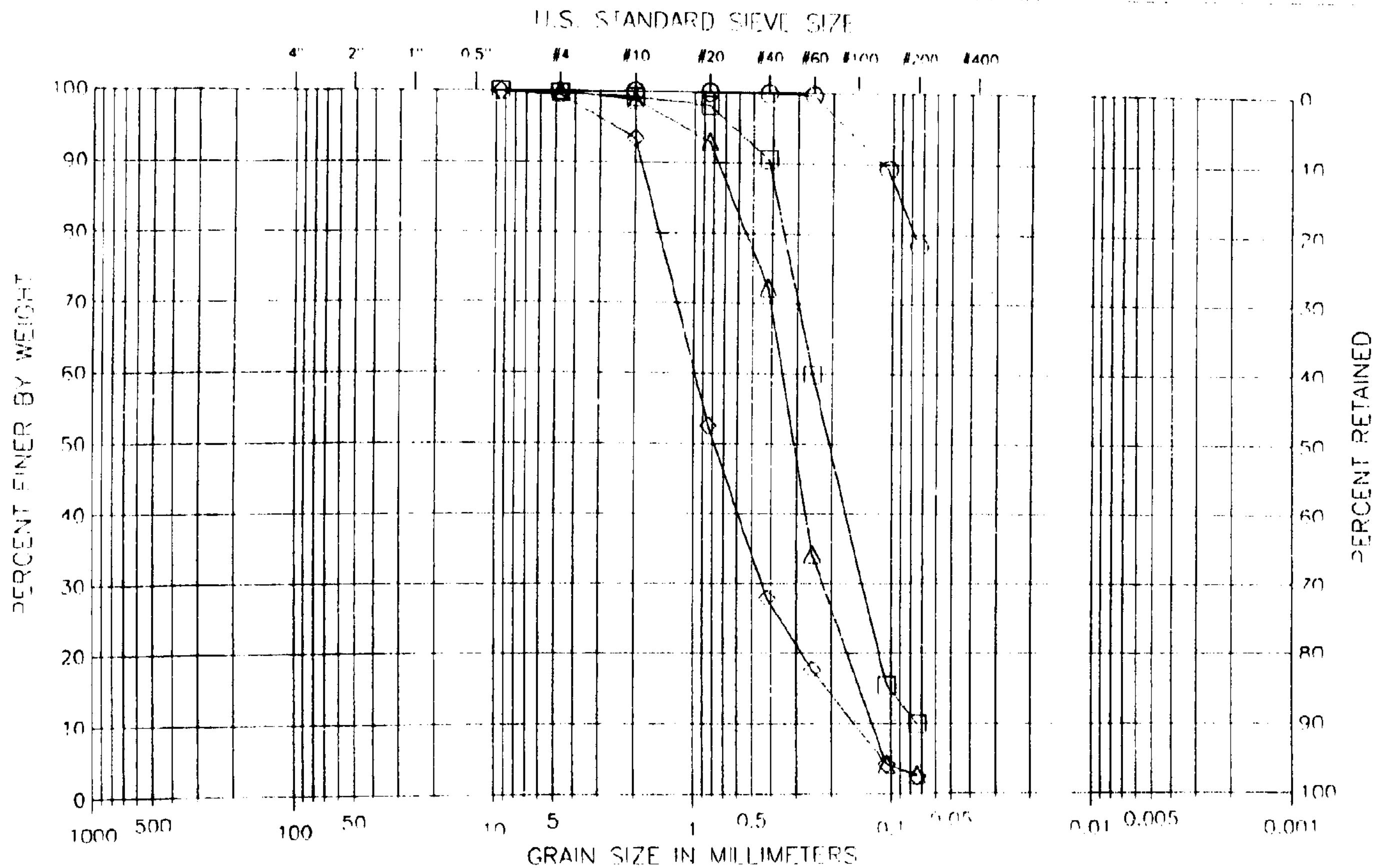


1000-307

KCSlip4 44035

SEA410565

Soil Technology, Inc.	**Grain Size Analysis**	Project : ARI/ Boeing Corporation SHEA Project No.: J-951 Location: Boeing Date : Fri Aug 16 1996



COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	

Symbol	Boring No.	Sample No.	Depth	Filename	Classification / Description	
-○-	SB	EMF2~~2~~4	0375	P662J	ML	silt with sand
-△-	SB	EMF2~~3~~5	0075	P662N	SP	Poorly graded sand
-□-	SB	EMF2~~3~~5	0175	P662O	SP-SM	Poorly graded sand with silt
-◇-	SB	EMF2~~3~~5	0250	P662P	SW	Well-graded sand

Description based [illegible] rain size only if no Atterberg Limits performed.

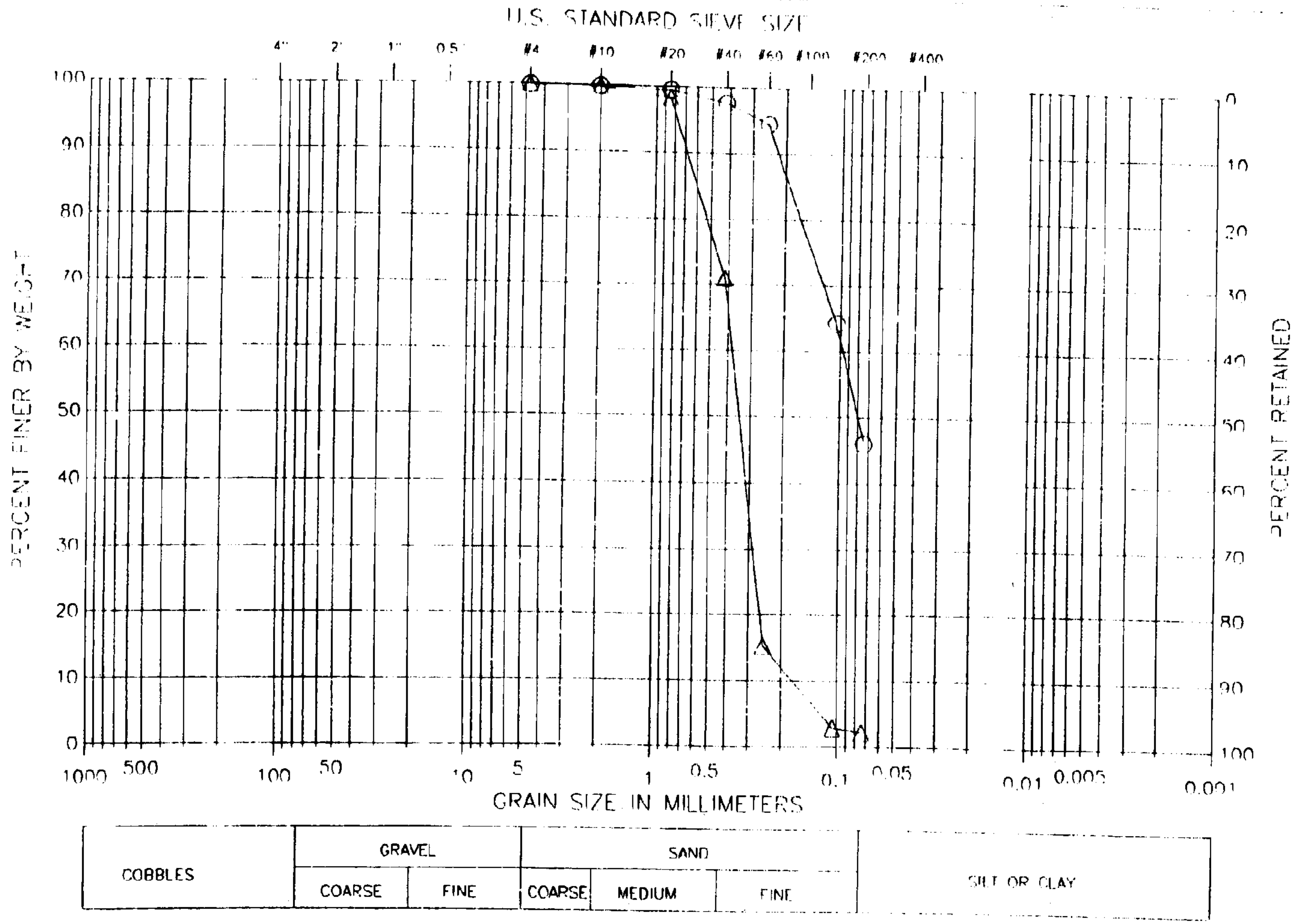
TF

Figure 5

Soil Technology, Inc.

Grain Size Analysis

Project : ARI/ Boeing Corporation SHEA
Project No.: J-95[illegible]
Location: Boeing
Date : Fri Aug 16 1996



Symbol	Boring No.	Sample No.	Depth	Filename	Classification / Description	
⊖	SB	EMF265 (FF)	0360	P6620	SM	Silty sand
△	SB	EMF07	0100	P690H	SP	Poorly graded sand

Description based on grain size only if no Atterberg Limits performed.

Figure 4

Appendix C –Report for Aquifer Pumping Test, EMF Plume on West Side of North Boeing Field

DRAFT

AQUIFER PUMPING TEST REPORT
EMF SITE/BOEING FIELD

PREPARED FOR
THE BOEING COMPANY
ENERGY AND ENVIRONMENTAL AFFAIRS

PREPARED BY
PROJECT PERFORMANCE CORPORATION
16935 SE 39TH STREET
BELLEVUE WA 98008

October 10, 2001

TABLE OF CONTENTS

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LIST OF FIGURES

DRAFT REPORT FOR AQUIFER PUMPING TEST
EMF PLUME ON WEST SIDE OF NORTH BOEING FIELD

1.0 INTRODUCTION

This report summarizes the field work and data analysis/interpretation for an aquifer pumping test performed near the west side of North Boeing Field. The general site vicinity is shown in Figure 1. This test was conducted to determine hydraulic properties of the aquifer underlying North Boeing Field in the area where the volatile organic compound (VOC) plume from the EMF site is located (along the western boundary with East Marginal Way). A site map showing the location of the pumping test site and layout of monitoring wells is shown in Figure 2.

The pumping test was conducted based on the recommendations of the project peer review team. The primary aquifer property of interest is the hydraulic conductivity. The conductivity determined from the test is one of the key parameters used in transport and degradation rate constant calculations, as well as for design of remedial actions if they are deemed necessary. The aquifer pumping test was used to evaluate a specific stratigraphic interval of the aquifer where the EMF VOC plume is present. This specific vertical interval of the aquifer is expected to have a higher hydraulic conductivity (relatively) than other portions of the aquifer (based on visual observations of the soil texture and comparison of grain size distributions).

1.1 Summary of Test Procedures

The aquifer pumping test was conducted by extracting water from one well (extraction well) and observing the drawdown in this well and four other wells (observation wells). The test was conducted in three parts consisting of a step-drawdown test, a constant rate test, and a recovery test. The step-drawdown test was conducted by pumping the extraction well at increasing flow increments and measuring drawdown over time in the extraction well.

The constant rate test was conducted by pumping the extraction well at a constant rate for a period of 24 hours. The constant rate test was started after the water elevation in the extraction well had fully recovered from the step-drawdown test (approximately 20 hours after the step test). The water levels in the five wells were monitored during the constant rate test. Water levels were monitored using pressure transducers and data loggers as well as manual measurements using an electronic depth sounder (e-tape).

The recovery test began immediately after completion of the constant rate test. The recovery test was conducted by measuring recovery of the drawdown in the extraction well and observation wells over time after cessation of pumping.

Well EMF WF-35, a four inch diameter well, was used as the extraction well. The following 2-inch diameter wells were used as observation wells:

EMF WF-27	29 feet from EMF WF-35
EMF WF-26	92 feet from EMF WF-35
EMF WF-28	174 feet from EMF WF-35
EMF WF-29	259 feet from EMF WF-35

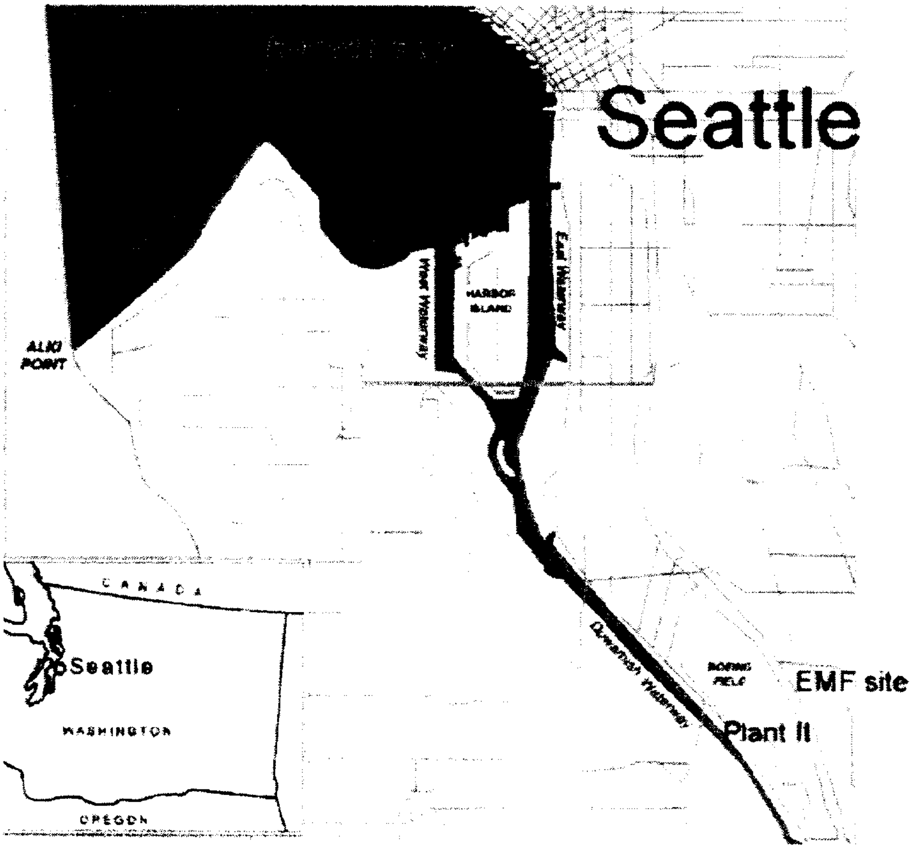


Figure 1. Site Vicinity Map

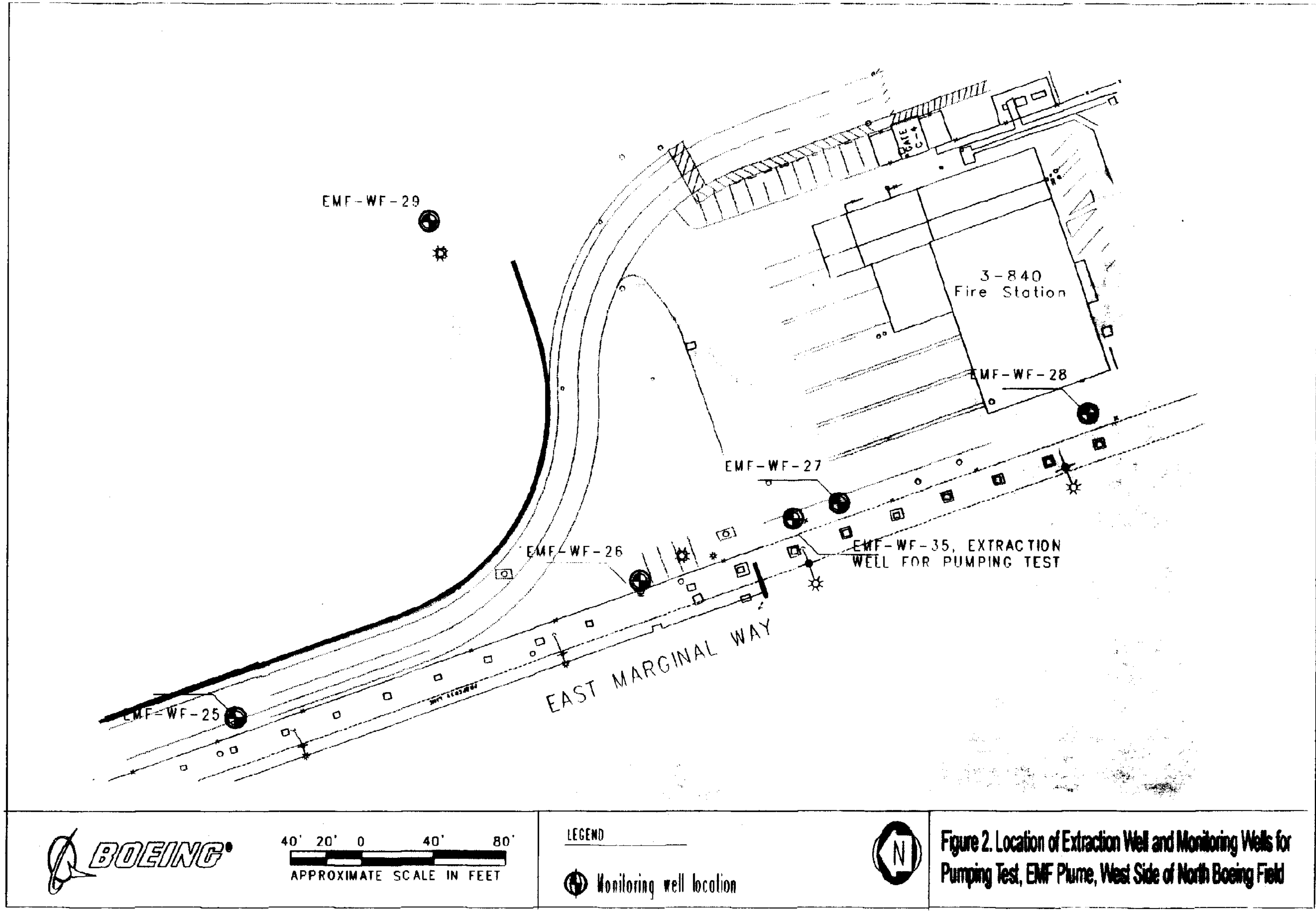


Figure 2. Location of Extraction Well and Monitoring Wells for Pumping Test, EMF Plume, West Side of North Boeing Field

1.2 Summary of Background Information

Some general site background information is briefly summarized in this section. Additional information, including boring logs/well construction details, grain size distributions of soil samples, and VOC plume cross-section data, is presented in Appendix A.

The site is located in the Duwamish valley, approximately 1,500 ft northeast of the Duwamish Waterway. The general stratigraphy at the site is as follows. The surface consists of the tarmac, which is underlain by varying depths of fill, ranging from approximately 3 to 8 feet in thickness. The fill is underlain by a silty zone, which extends to a depth of approximately 15 to 20 feet below ground surface (bgs). Materials in this zone appear to consist of approximately 50% fines (i.e., silt- and clay-sized particles). This zone is underlain by uniform fine to medium sands, which extend to a depth of approximately 50 feet bgs. Based on particle-size analyses of samples collected from this zone, this fine to medium sand zone contains approximately 1% fines (see Appendix A). This zone is then underlain by interbedded sands and silts. Appendix A includes a cross section showing the stratigraphy encountered in this area. The stratigraphy described here and Appendix A is identical with the results of two previous geotechnical investigations conducted in the immediate area.

Rough estimates of the hydraulic conductivity of the aquifer in this area were previously made based on evaluation of grain size distributions and the results of slug tests. Based on these data, the hydraulic conductivity was estimated to be in the range of 60 to 170 ft/day (2 x 10^{-2} cm/sec to 6 x 10^{-2} cm/sec). These initial estimates contain large uncertainty, which is one of the reasons the peer review team recommended conducting an aquifer pumping test.

1.3 Organization

The remainder of this report describes how the pumping test was performed. Section 2.0 identifies the equipment used to conduct the test. Section 3.0 presents the specific field procedures used. Section 4.0 describes the analysis of data and conclusions derived from the test. Section 5.0 presents conclusions derived from the test and data analysis. Appendix A provides some relevant site background information. Appendix B presents the data analysis plots used to estimate the hydraulic parameters of the aquifer. Appendix C presents the water level response data. Appendix D presents the laboratory data sheets for the samples analyzed.

2.0 EQUIPMENT

The equipment used to perform the aquifer pumping test is identified in Table 1. The submersible pump, variable speed drive, and two of the pressure transducers were rented from Instrumentation Northwest. The four double walled storage tanks (total capacity of 70,000 gallons) were rented from Baker Tanks. The generator was rented from Prime Power. The data loggers and additional pressure transducers used were Boeing-supplied equipment.

Piping was connected to the discharge port on the submersible pump and routed through the flow meter/totalizers, gate valve, and sample port to the four Baker tanks. A ball valve was installed at the base of the hose leading into each of the Baker tanks.

Table 1. Equipment Used

Item	Quantity	Comments
4-inch submersible pump	1	Maximum capacity of approximately 50 gallons per minute at 50 feet head. Includes discharge piping, electrical wiring, and foot valve to prevent drainage into well.
Variable frequency drive	1	Capable of operating pump up to 100 hertz.
Large electrical generator	1	Diesel generator was used to insure constant and steady supply of electricity.
Gate valve	1	Installed on discharge line.
Totalizer/flow meter	2	Used to measure discharge from well.
Sample tap	1	Installed on discharge piping downstream of flow meter and used to collect water quality samples.
8-channel data logger	2	Used to collect and store time-stamped measurements from pressure transducers.
Vented, submersible pressure transducers	5	Installed in extraction well and observation wells and used to measure water level. Transducers were capable of measuring water levels to 0.01 ft (0.0043 psi).
Well sounder	1	Used to measure depth to water in extraction well and observation wells. Sounder was capable of measuring water levels to 0.01 ft.
pH, temperature, and specific conductance meters	1 ea.	Used for field measurements of pH, temperature, and specific conductance. Included calibration solutions.
40-mL volatile organic analysis vials	8	Used to collect water samples for VOC analysis.
Stop watch	1	Used to measure elapsed time during test.
Steel drum	1	55-gallon drum was used to collect quantity of water over timed interval to verify accuracy of flow meter.
Double-walled 17,600 gallon capacity Baker tanks	4	Used to collect water pumped from extraction well. Included pipe, hose, and valves from well head to tanks.

3.0 TEST PROCEDURES

The following sections describe the specific procedures used for each of the three tests:

- step-drawdown test,
- constant discharge test, and
- recovery test.

All test procedures were conducted in accordance with Project Performance Corporation's Foreign Object Debris/Damage (FOD) Awareness/Prevention Program, which was part of the work plan for the pumping test. All staff participating in field activities associated with the pumping test received FOD awareness training prior to working on the site.

3.1 Step-Drawdown Test

An e-tape was initially used to measure depth to water in the extraction well and the four observation wells before the placement of the pump and the pressure transducers. Before measuring depth to water, extensions to the well casing of approximately one foot were placed on each of the monitoring wells to bring them up out of the flush-mount well completions.

The submersible pump was then set in the extraction well near the top of the screen interval (approximately 7 feet above the well bottom). The top of the well was covered with a two-hole compression well seal; one hole for the discharge pipe and one hole for the transducer port. The pump was wired through the variable frequency drive (VFD) controller to the generator.

Transducers were placed in all five wells between 7 and 15 feet below the static water level and secured at the top to prevent movement during the test. Transducers in the extraction well and the three closest observation wells (EMF WF 35, 26,27, 28) were connected to one data logger. Monitoring well EMF WF-29 was connected to a second data logger because it was further from the extraction well than the length of the transducer cable. Both data loggers were programmed to collect data at different intervals over the testing period.

The pump was turned on for a few minutes to verify that all components were operating correctly. After the pump was shut off, the transducer in the extraction well was reset at a lower depth. Time was allowed for the extraction well to achieve full recovery before starting the step test.

The step test was performed using three steps. Each step was run until the depth to water in the extraction well remained constant. Flow rates, the frequency (Hz) setting on the variable frequency drive (VFD) (i.e., the relative speed to drive the motor), and equilibrated depth to water level in the extraction well for each step are shown in Table 2. During this step test, one of the flow totalizers became stuck, which significantly increased the operating head on the pump (the flow of water through the partially restricted totalizer was audible).

Problems were encountered when the VFD was set to its maximum frequency of 100 Hz. At this maximum setting, the pump would run for a while and then kick off with a motor overload message on the VFD. The same problem was apparent at a 95 Hz setting, although the pump ran longer. At a 90 Hz setting the pump ran reliably for about 90 minutes of testing. Based on discussions with the manufacturer it was decided to run the pump at an 85 Hz setting for the constant rate test.

Table 2. Step Test Parameters

Flow Rate	Frequency Setting on VFD, Hz	Final Depth to Water
20 gpm	51.4	11.20 ft
30 gpm	69.6	12.28 ft
40 gpm	90.4	13.84

3.2 Constant Discharge Test

After allowing adequate time for the water level in the extraction well to recover to pretest levels, preparations were made to start the constant discharge test. A review of the step test data, as well as the problems with the pump shutdown at VFD settings above 90Hz, dictated a VFD setting of 85 Hz. The flow meter reading at this setting was 42 gallons per minute (gpm). This flow meter reading was calibrated with two tests to fill a 55 gallon drum and found to be about 5% low. After calibration, the actual pumping rate was determined to be 44.2 gpm.

Prior to starting the test, the data loggers were reprogrammed to collect pressure measurements at appropriate intervals, totalizer values were recorded, and depth to water was measured in all five wells. The pump was started for the constant discharge test on September 12 at 10:24 a.m. Fifty gallons of water were pumped into a 55-gallon steel drum on a timed basis in order to calibrate the flow meters. This procedure was repeated just prior to shutting off the pump at the end of the test. In addition to the data collected by the data loggers, the depth to water was measured by hand at all five wells, flow rate and totalizer totals were recorded, and controller frequency was noted at regular intervals. The hand recorded data were collected at two minute intervals for the first ten minutes, ten minute intervals for the next twenty minutes, a thirty minute interval (in the extraction well), and then hourly until the end of the test (in all of the wells).

Hand-measured depth to water readings compared very closely to the readings obtained by the data loggers in wells WF-26 and WF-28. Exceptions ranging up to 0.15 feet were noted in wells WF-27, WF-29, and WF-35. The cables leading from the transducers in those wells had a thick Teflon outer sleeve making them quite stiff. This resulted in a significant arch in the cable where it came up out of the well riser, making it difficult to securely fasten the cable preventing any movement in the transducer position. Review of the data logger output indicated the point at which the movement of the transducer occurred and the numbers were adjusted accordingly from that point until the end of the test based on the hand measured depth to water readings.

Water quality measurements were made with samples collected from the sample port a few hours after the start of the constant discharge test at 1:11 pm. These measurements were made after first calibrating the pH meter and total dissolved solids (TDS) meter using standards. Water quality measurements were made again on September 13 at 4:49 a.m., 6:45 a.m. and 10:00 a.m. Water quality measurements are shown in Table 3.

During the first and fourth water quality parameter sampling, samples were also collected and sent to ARI Laboratories and analyzed for VOCs, anions, and cations. Results from these analyses are shown in Table 4. Volatile organic samples were collected by filling two 40-ml vials from the sample port. Anion and cation samples were collected by filling a 250-ml bottle from the sample port. Sample collection, handling, shipping, and analyses were accomplished in accordance with the Project Quality Assurance Plan.

Table 3. Water Quality Parameters

Date/Time	Temperature	TDS mg/l	pH
September 12, 2001, 1:11 p.m.	16° C	300	6.87
September 13, 2001, 4:49 a.m.	14° C	300	6.95
September 13, 2001, 6:45 a.m.	14° C	310	6.85
September 13, 2001, 10:00 a.m.	15° C	300	6.90

Table 4. Analytical Results

Analyte	September 12, 2001, 1:11 p.m. Sampling	September 13, 2001, 10:00 a.m. Sampling
Vinyl Chloride	260 ug/L	320 ug/L
1,1 Dichloroethene	12 ug/L	12 ug/L
trans 1,2 Dichloroethene	37 ug/L	38 ug/L
cis 1,2 Dichloroethene	1,300 ug/L	1,300 ug/L
trichloroethene	< 1 ug/L	< 1 ug/L
2-Butanone	9.8 ug/L	9.3 ug/L
Bromide	0.1 mg/L	0.1 mg/L
Fluoride	0.1 mg/L	0.1 mg/L
Chloride	18.7 mg/L	19.5 mg/L
Sulfate	2.2 mg/L	1.7 mg/L
Barium	0.013 mg/L	0.012 mg/L
Calcium	30.8 mg/L	31.3 mg/L
Iron	20.9 mg/L	21.6 mg/L
Magnesium	14.4 mg/L	14.9 mg/L
Potassium	5.4 mg/L	5.5 mg/L

Evaluation of the data in Table 3 and Table 4 indicates that there was no significant leakage of water from other aquifer zones (with different water chemistry) during the time period tested. The difference in temperatures was likely caused by the difference in temperature of the container in which the sample was placed.

Flow rate decreased slightly, perhaps 0.5 gallons per minute, during the second half of the test due to additional head loss from the additional piping required to reach the two Baker tanks that were about 100 feet further away.

The pump was turned off at 10:30 a.m. on September 13, 2001. Final totalizer values were recorded at that time. During the constant discharge test, approximately 64,000 gallons of water were pumped into the Baker tanks.

3.3 Recovery Test

Just prior to turning off the pump at the end of the constant discharge test, the data loggers were reprogrammed for the recovery test. As soon as the pump was turned off, data collected by the data loggers was augmented with one round of manual depth to water measurements taken in all five wells. Data continued to be collected for twenty four hours after pump shutdown.

At the end of the recovery test, all data was downloaded from the data loggers, equipment and piping was disassembled, and the site was cleaned up.

4.0 DATA REDUCTION AND ANALYSIS

This section summarizes the results of the step-drawdown test, constant rate pumping test, and the recovery test. These tests were conducted to determine hydraulic properties of the aquifer at the west side of North Boeing Field where the plume from the EMF site is located. The basic model for data analysis of the pumping test results is based on a solution of the transient ground-water flow equation in cylindrical coordinates, given some boundary and initial conditions. A steady state solution to the Laplace equation is the Thiem equation. For the non-steady state i.e., transient flow conditions, the most common solutions are the Theis and the Jacob methods, both of which assume constant pumping rates for the duration of the test. Modifications to these basic methods have been developed to account for leakage from other water bearing zones (Hantush-Jacob method).

4.1 Basic Assumptions for Pumping Test Equations/Data Analysis

In order for the aquifer pumping test equations (and corresponding data analysis) to be valid, certain assumptions must be made about the aquifer, and the extraction and observation wells. The following general assumptions are made for the basic equations used for analysis of the pumping test results:

- The aquifer has a seemingly infinite areal extent.
- The aquifer is homogeneous, isotropic and of uniform thickness over the area influenced by the pumping test.
- Prior to pumping, the potentiometric surface is (nearly) horizontal over the area influenced by the pumping test.
- The aquifer is pumped at a constant discharge rate.
- The pumped well fully penetrates the entire thickness of the aquifer and is fully screened, thus receiving water from the entire thickness of the aquifer by horizontal flow.
- Flow towards the well is radial, i.e., equipotential surfaces are plane, concentric cylinders around the well.
- Darcy's equation is applicable, i.e., laminar flow conditions exist in the aquifer.
- The pumped well is 100 percent efficient (i.e., there are no well losses).
- Transmissivity and storage coefficients remain constant with time.

The following additional assumptions are required for the Theis solution to the transient groundwater flow equation:

- The aquifer is confined.
- The flow to the well is in unsteady (transient) state, i.e., the drawdown differences with time are not negligible nor is the hydraulic gradient constant with time or distance.
- The water removed from storage is discharged instantaneously with decline of head.
- The diameter of the pumped well is very small (i.e., insignificant), thus the storage in the well bore can be neglected.
- The formation receives no recharge from any source.

The following additional assumptions are required for the Jacob solution to the transient groundwater flow equation:

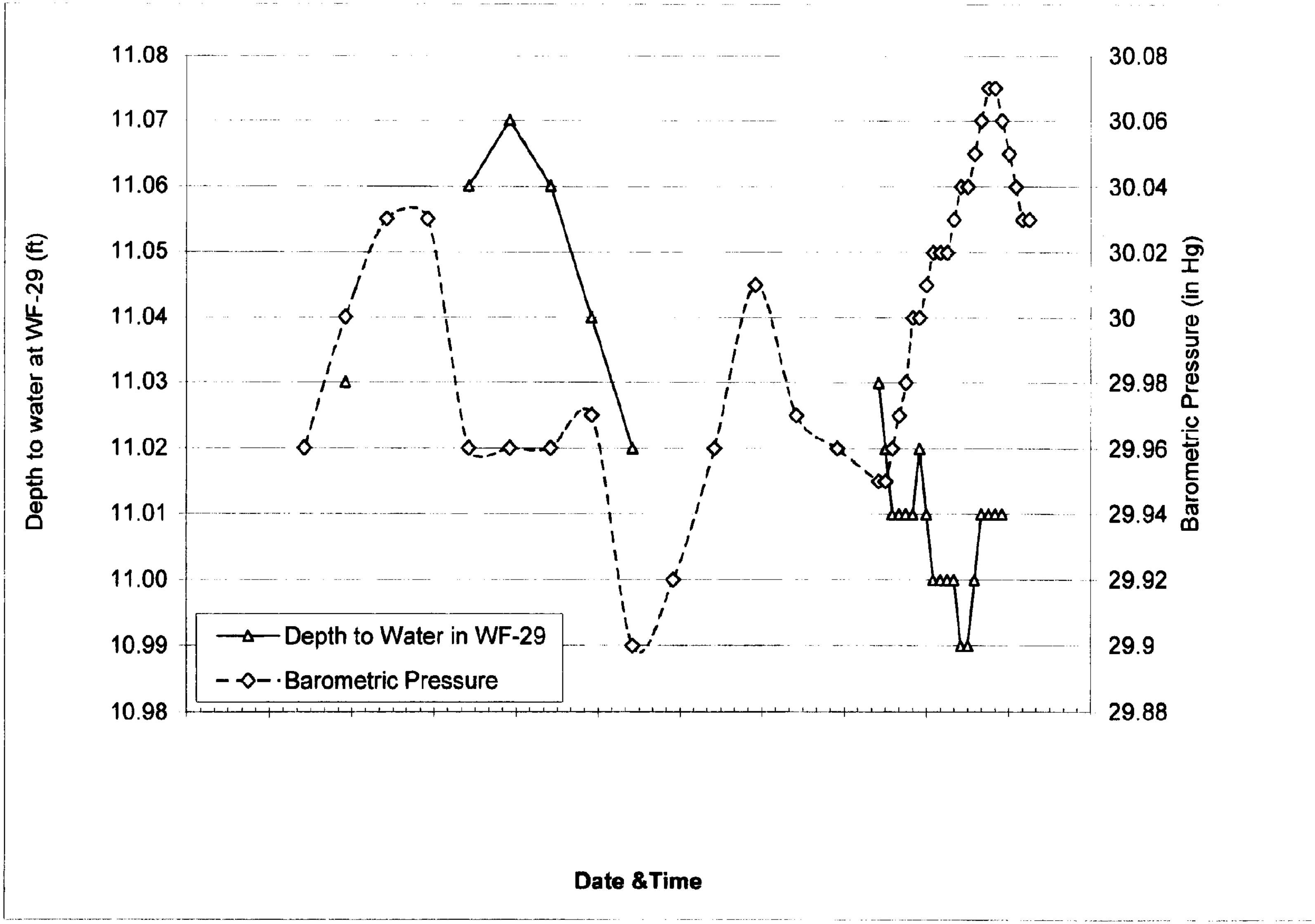
- The same conditions are assumed that apply to the Theis method.
- The values of u (u is the well function W(u) of the Theis method) are small ($u < 0.01$) (the radial distance [r] from the pumping well to the point of concern is small and the time [t] since pumping started is large, therefore, later time hydraulic response data are used in the analysis).

In practice not all of these assumptions are fully met for most pumping tests. Careful analysis of the data and judicious selection of curve fitting sections, however, allow for reasonable parameter estimates even in cases where some of the assumptions are not met. The most important assumptions to be aware of in the data analysis are the potential for leakage or boundary effects and selecting an appropriate straight line section for the Jacob analysis method. For the purposes of this aquifer test, data analysis, and project objectives, the assumptions are met in an approximate manner (although not fully) and parameter estimates derived are believed to be representative of the actual aquifer conditions. The aquifer was assumed to have a uniform thickness of 35 feet for the data analysis.

4.2 Validity of Tests

Water level trends, precipitation records, and barometric pressure changes were collected before, during, and after the aquifer tests. There was no precipitation within the 24 hours before, during the pumping test, or during the recovery period. Appendix C contains records collected before, during, and after the tests. Table 5 lists the water level at each well just before (09/10/01 at 12:30) and at the completion of the aquifer tests (09/14/01 at 10:16). The depth to water for wells WF-26, WF-27, and WF-28 shows no significant change. The furthest well, WF-29, had not quite recovered to the initial value for depth to water. The depth of the transducer at the pumping well WF-35 and WF-29 moved slightly during the test (see Section 3.2). The barometric pressure during the pumping test ranged from 29.92 to 30.07 inches of mercury (Hg) The test began and ended at 30.03 inches of Hg. The change in barometric pressure during the test is not considered significant to impact the calculations of the aquifer properties (see Figure 3).

Figure 3. Barometric Pressure Data and Depth to Water at WF-29



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The Jacob Straight-Line Method is applicable only when steady-shape conditions are met at the observation well (i.e., u in the well function W(u) is small). Steady-shape conditions prevail at a well when the cone-of-depression (at that location) maintains a "steady shape", although additional drawdown may still be occurring. For steady-shape conditions, the Jacob Straight-Line Method can be applied. If the drawdown data collected during this time interval of hydraulic response are plotted on a semilogarithic graph, the data points should define a straight line. This simplifies calculation of the aquifer's hydrogeologic properties. To estimate when steady-shape conditions have arrived at each observation well, u (the well function) is set equal to 0.1. Substituting values of 0.002 (dimensionless) for storage coefficient (S) and 6.61 ft^2/min for transmissivity (T) (derived from the Hantush-Jacob analysis of well WF-27), Eq. 1 reduces to Eq. 2, where R_1 is the distance from the pumping well in feet, and t is the time to steady-shape in minutes.

$$u = (R_1^2 S) / (4Tt) \qquad \text{Eq. 1}$$

$$t(min) = (0.000756)\, R_1^2 \qquad \text{Eq. 2}$$

Table 5 lists calculated times when steady-shape was expected to have arrived at each observation well. Steady-shape was reached early enough to allow the Jacob Straight-Line Method to estimate aquifer parameters.

Table 5. Validity of Measurements

Well	Distance to Pumping Well (feet) and direction	Initial Depth to water (feet)	Final Depth to water (ft) (24 hour recovery)	Time to Steady-shape (minutes)	Duration of Pumping Test (minutes)	Drawdown in feet after 24 hours of pumping
WF-35	NA	15.67	14.54*	NA	1446	4.0
WF-27	29 -North	14.02	14.03	1	1446	0.48
WF-26	92 -South	9.55	9.54	6	1446	0.37
WF-28	174 -North	7.05	7.02	23	1446	0.30
WF-29	259 - West	15.37	15.44*	51	1446	0.21

Notes: * = transducer moved during test; NA = Not Applicable

4.3 Step-Drawdown Test

The results of the step-drawdown test were used to determine the pumping rate for the constant rate test. The maximum pumping rate that could be sustained was at a flow meter reading of 42 gallons per minute. The flow meter was calibrated by pumping to a 55 gallon drum and the actual pumping rate for the constant rate test was measured at 44.2 gallons per minute.

The drawdown measurements from the step drawdown test are shown in Figure 4. The three pumping rate steps tested were 20, 30 and 40 gpm. The last step at 50 gpm failed because the pumped stopped. The data for each of the steps is presented in Figure 5. This figure illustrates that the well indicates a nonlinear (quadratic) increase in drawdown with increased pumping. The specific capacity (yield/drawdown) of the well decreased by 30% as the pumping rate increased from 20 to 40 gpm. This nonlinear response probably results because the well is not 100% efficient and is not fully penetrating.

4.4 Constant-Rate Pumping Test

The constant rate pumping test began on September 12, 2001, at 10:24 a.m. and was completed on September 13, 2001, at 10:30 a.m. See Appendix C for the dates, times, and water levels recorded by the data logger.

There are several graphical-solution methods to determine aquifer conductivity from pumping test data. The Cooper-Jacob, Hantush-Jacob, Neuman, and Theis curves were reviewed for applicability for this pumping test. The software product AquiferTest by Waterloo Hydrogeologic was use to match the pumping test data onto the appropriate curve to determine transmissivity (T), and storativity (S). The hydraulic conductivity was subsequently calculated (from the transmissivity) using an aquifer thickness of 35 ft. Additional calculations (in an Excel spreadsheet) were used to calculate the distance-drawdown analysis, and to cross check the results from the AquiferTest software package.

The first estimate of the aquifer conductivity was obtained using the Cooper-Jacob Distance-Drawdown method (see Figures 6 and 7). A conductivity of 278 ft/day was calculated from the drawdown results at 12 hours and a value of 329 ft/day was calculated from the results at 24 hours. Note the high correlation (R^2=0.97 and 0.98) of the four data points for the regression analyses at both times of 12 and 24 hours.

The data in Figures 6 and 7 include the response data from observation wells in the North, South and West directions from the extraction well. The data from the extraction well (WF-35) are not included in the regression (and do not fit the regression line) because the response of the extraction well is affected by partial penetration of the well and well inefficiencies. These two factors induce additional drawdown at the extraction well (as observed) and the total drawdown is not representative of the aquifer response at the extraction well. The high degree of correlation using data from different directions indicates little anisotropic effects in the horizontal plane. The reasonably close fit of data points to the regression line suggests that the hydraulic response of the aquifer in the immediate area is not significantly affected by the scale of heterogenities that may be present (it appears as a nearly a homogeneous hydraulic response).

Figure 4. Step Test Drawdown Results

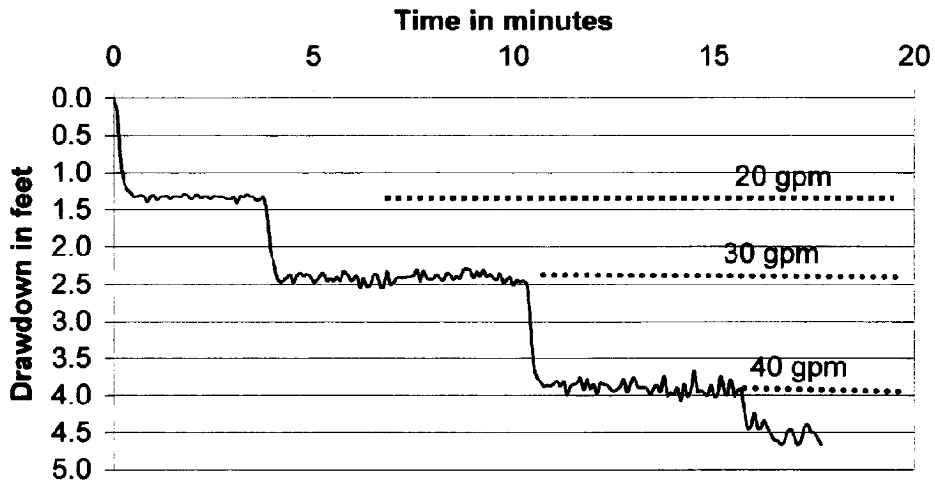


Figure 5. Data Analysis of Step Test Results

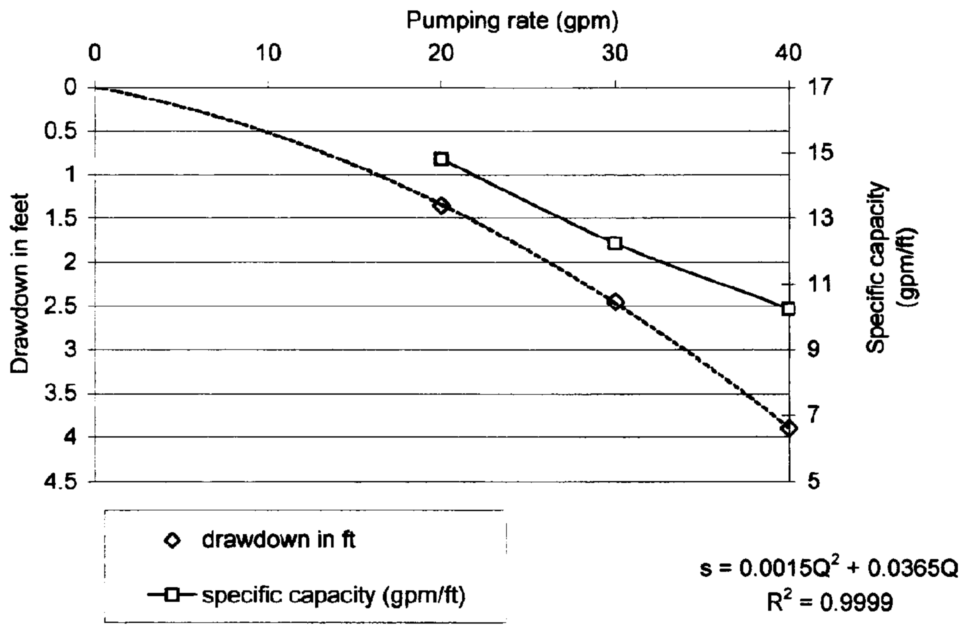
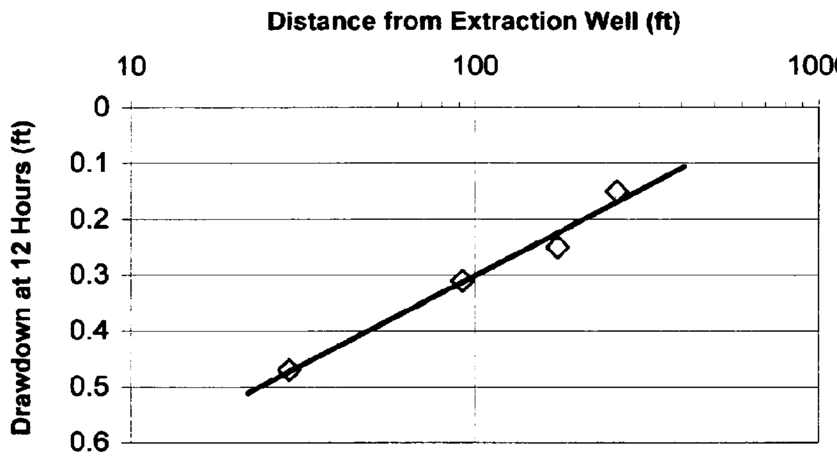


Figure 6. Distance-Drawdown Analysis at 12 hours

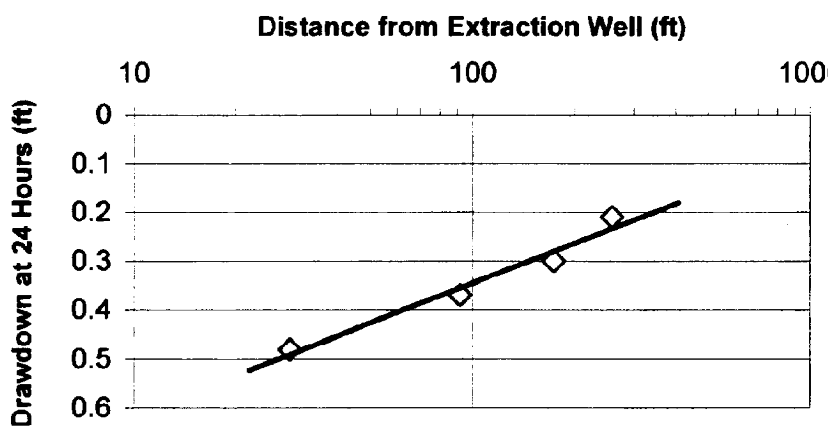


$$T = \frac{2.3\,Q}{2\pi\,\Delta s}$$

s = -0.32Log(r) + 0.94
$R^2 = 0.98$

T = 9,746 ft^2/day
K = 278 ft/day
S = 0.015

Figure 7. Distance-Drawdown Analysis at 24 hours



$$T = \frac{2.3\,Q}{2\pi\,\Delta s}$$

s = -0.27Log(r) + 0.88
$R^2 = 0.97$

T = 11,532 ft^2/day
K = 329 ft/day
S = 0.008

Graphs of the solutions using Cooper-Jacob Time-Drawdown, Hantush-Jacob, Neuman, and Theis curves are presented in Appendix B. The results of these analyses are listed in Table 6 along with the aquifer conditions that define each method. Well WF-27 was the first well analyzed and all four graphical solutions were applied to drawdown data from this well. For this single well, two of the data analysis methods (the Hantush-Jacob Method and the Neuman Method) do not fit any of the matching curves well. When forced to match a type curve, these two methods provide estimates of hydraulic conductivity that are about 20% of all the other estimates (a factor of 5 lower). We were unable to find any reason why these parameter estimates are so much different. The recovery data from this well, as well as the corresponding estimated hydraulic conductivity, are consistent with the other estimates.

In an attempt identify possible errors in the data or the data analysis methods used, the Theis drawdown equation was used to calculate the expected drawdown using the following parameters: pumping rate equal to 44.2 gpm, conductivity equal to 354 ft/day, aquifer thickness equal to 35 ft, storage coefficient equal to 0.002 and radial distance to the extraction well equal to 29 feet. The results of these calculations are presented in Figure 8, which show a reasonable fit to the measured drawdown from about 5 minutes to 1330 minutes of the pumping test. Based on this evaluation of these two suspect parameter estimates, they are deemed unreliable and are not considered further.

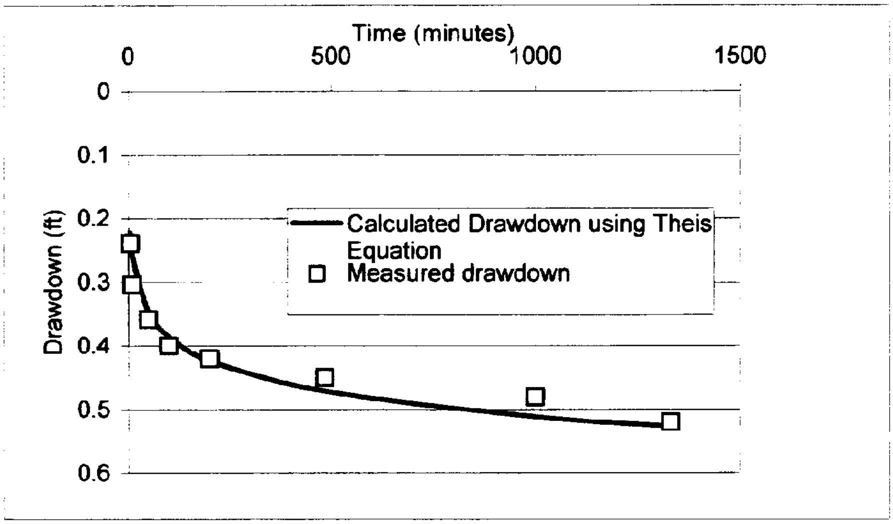
After reviewing the results for the other wells, it was decided that the Cooper-Jacob Time-Drawdown and the Hantush-Jacob methods best define the conditions of the aquifer. The drawdown data from the other three wells were evaluated using just the Cooper-Jacob Time-Drawdown and Hantush-Jacob graphical solutions.

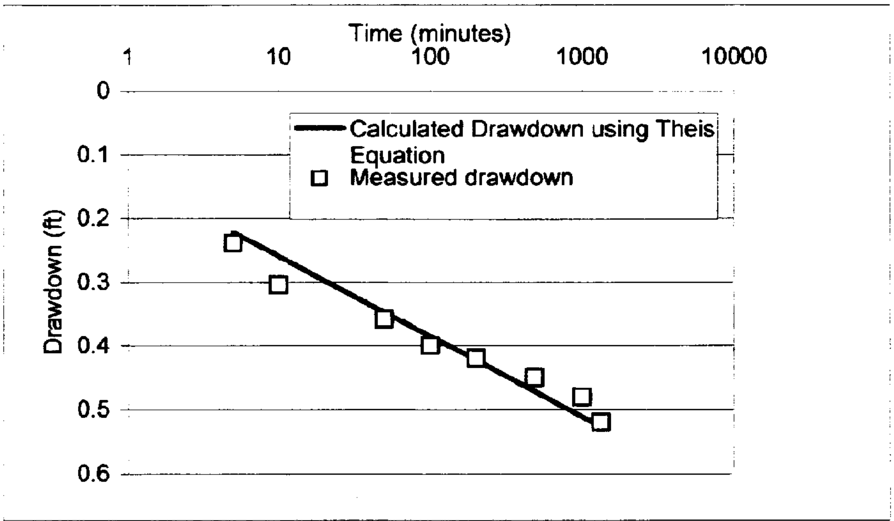
Table 6. Graphical Solutions for Transmissivity, Conductivity, and Storage Coefficient

Well	**Distance to Pumping Well (ft)**	**Distance - Drawdown**	**Hantush-Jacob**	**Cooper-Jacob**	**Theis**	**Neuman**
	Conditions	Confined	Confined, Leaky	Confined, small r, large time	Confined	Unconfined
WF-35	NA		NA	NA	NA	NA
WF-27	29	K = 278 ft/day S = 0.015 @12 hours	K=78 ft/day T=6.6ft²/min S=0.0006	K=425 ft/day T =7.1ft²/min S=0.0004	K=270ft/day T=6.6ft²/min	K=84ft/day T=2.1ft²/min
WF-26	92		K=533ft/day T =13 ft²/min S=0.0014	K=433ft/day T=11 ft²/min S=0.0022	NP	NP
WF-28	174	K = 329 ft/day S = 0.008 @24 hours	K=443ft/day T =11 ft²/min S=0.0022	K=482ft/day T=12 ft²/min S=0.0020	NP	NP
WF-29	259		K=540 ft/day T=13 ft²/min S=0.003	K=425ft/day T =10 ft²/min S=0.007	NP	NP

Notes: NA = Not Applicable; NP = Not Performed, K is hydraulic conductivity, T is transmissivity, S is storage coefficient (dimensionless)

Figure 8. Comparison of Theis Drawdown Equation with Measured Values for WF-27





Q =44.2 gpm, K=354 ft/day, radial distance = 29 ft, aquifer thickness =35 ft
Storage coefficient = 0.002

4.5 Recovery Test

After the pump was shut down at the completion of the constant-rate pumping test, the data loggers recorded the rise in water levels at all wells. This rise in water levels is known as residual drawdown (s' on graphs). Analysis of the residual drawdown allows for an independent check on the results of the pumping test.

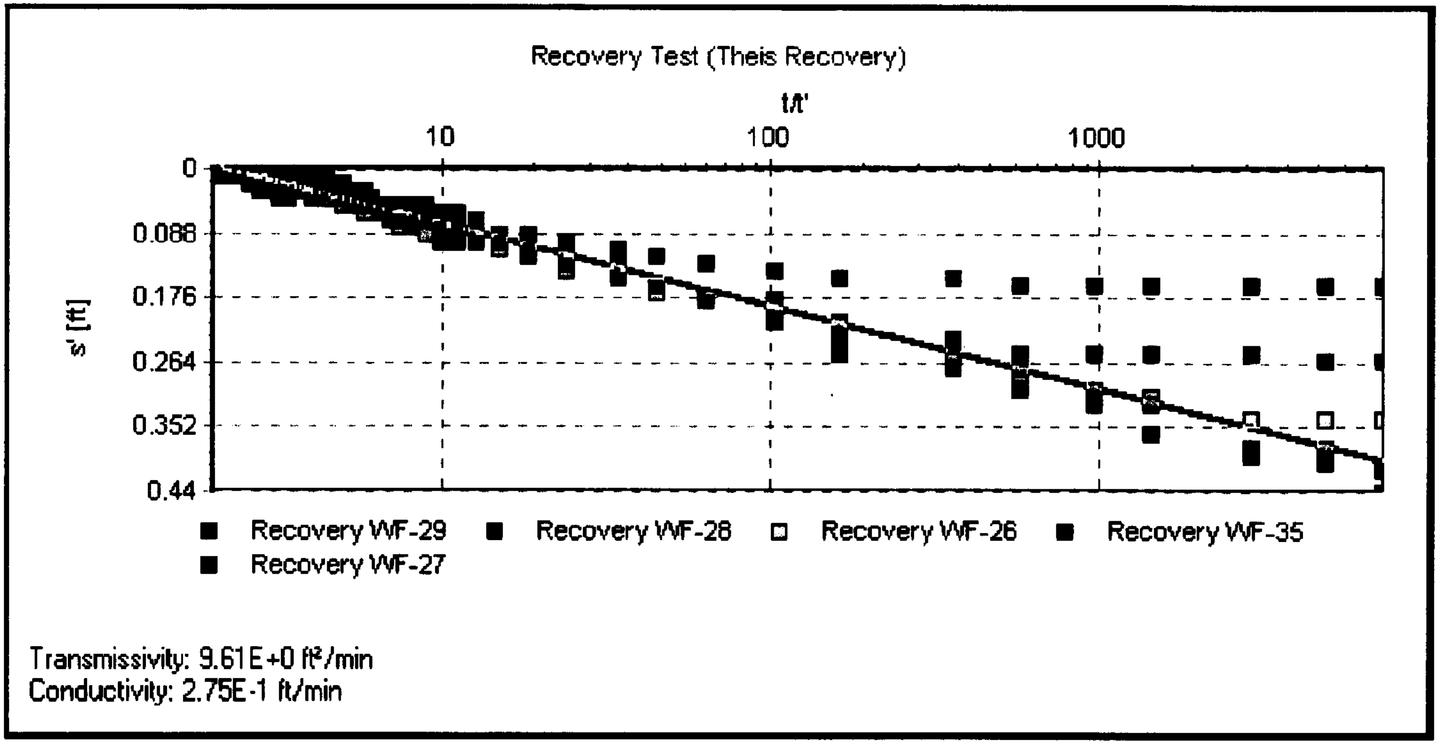
The recovery test began on September 13, 2001, at 10:29 a.m. and was completed on September 14, 2001, at 10:12 a.m. See Appendix C for the dates, times, and water levels recorded by the data loggers. Again the software package AquiferTest was used to calculate transmissivity. The process constituted fitting a straight line to the measured data and the software calculates the corresponding transmissivity. The assumptions for the recovery analysis to be valid are the same as the drawdown test. The results of the graphical solution for the recovery data using the Theis recovery graph are listed in Table 7. The first estimate of the transmissivity was obtained using Figure 9. This figure contains the recovery data from all of the wells, and a "typical" line was fitted to the data. A more detailed calculation of the transmissivity based on the residual drawdown at each individual well was then completed. The graphs are contained in Appendix B, and the results are listed in Table 7. These results agree well with the results from the constant rate pumping test that are listed in Table 6.

Each of the recovery test data plots indicates that the intersection of the zero residual drawdown (s') occurs at a t/t' ratio that is not equal to the ratio of t/t'=1. Typically the intersection is around 2.5 to 3 on the t/t' axes. This result is an indication of recharge to the aquifer during the test. Based on the understanding of the site conditions it is expected that the recharge is derived from leakage from overlying/underlying lower permeability zones.

Table 7. Graphical Solutions for Conductivity using Recovery Test Data

Well Name	Hydraulic Conductivity (ft/day)
WF-35	372
WF-26	396
WF-27	325
WF-28	383
WF-29	416
Graph using data from all wells	396

Figure 9. Graph of Recovery Test Data from All Wells



K = 396 ft/day

5.0 CONCLUSIONS

The data analysis of the aquifers hydraulic response provides estimates of the hydraulic conductivity with a mean value of 402 ft/day (of the estimates deemed reliable) and a standard deviation of 78 ft/day. The observed hydraulic response of the aquifer is consistent with the expected response as a leaky confined aquifer. Based on the these data, the hydraulic conductivity of the aquifer is expected to be approximately 400 ft/day (1.4×10^{-1} cm/sec).

The water quality parameters tested during the aquifer pumping test remained relatively unchanged over the 24 hour pumping period. The results are very similar to prior data collected in the immediate area. The water contains high levels of iron (presumable dissolved iron because the water was clear on pumping but orange after aeration and storage) so the redox conditions of the aquifer are expected to be strongly reducing. A leakage response appears to have been observed in the extraction well. This conclusion is based on the shape/inflections of the time vs. drawdown curve and the time ratio (t/t') intercept of the zero residual drawdown (s') in the recovery test. However, very little change in the VOC levels were observed for the two samples collected early and late in the test. A modest increase in vinyl chloride was measured (approximately 23% increase) but most other parameters remained about the same (VOCs, cation, and anions).

Given that the VOC plume is highly stratified and that all samples from about 20 to 30 feet bgs are near detection limits for VOCs, the lack of any dilution from the overlying zone of clean water is an indication that the leakage probably comes from the lower zone rather than the upper zone. The observed increase in vinyl chloride is consistent with this interpretation because the deeper Geoprobe samples from the area had increased vinyl chloride levels.

Appendix A

Background Information

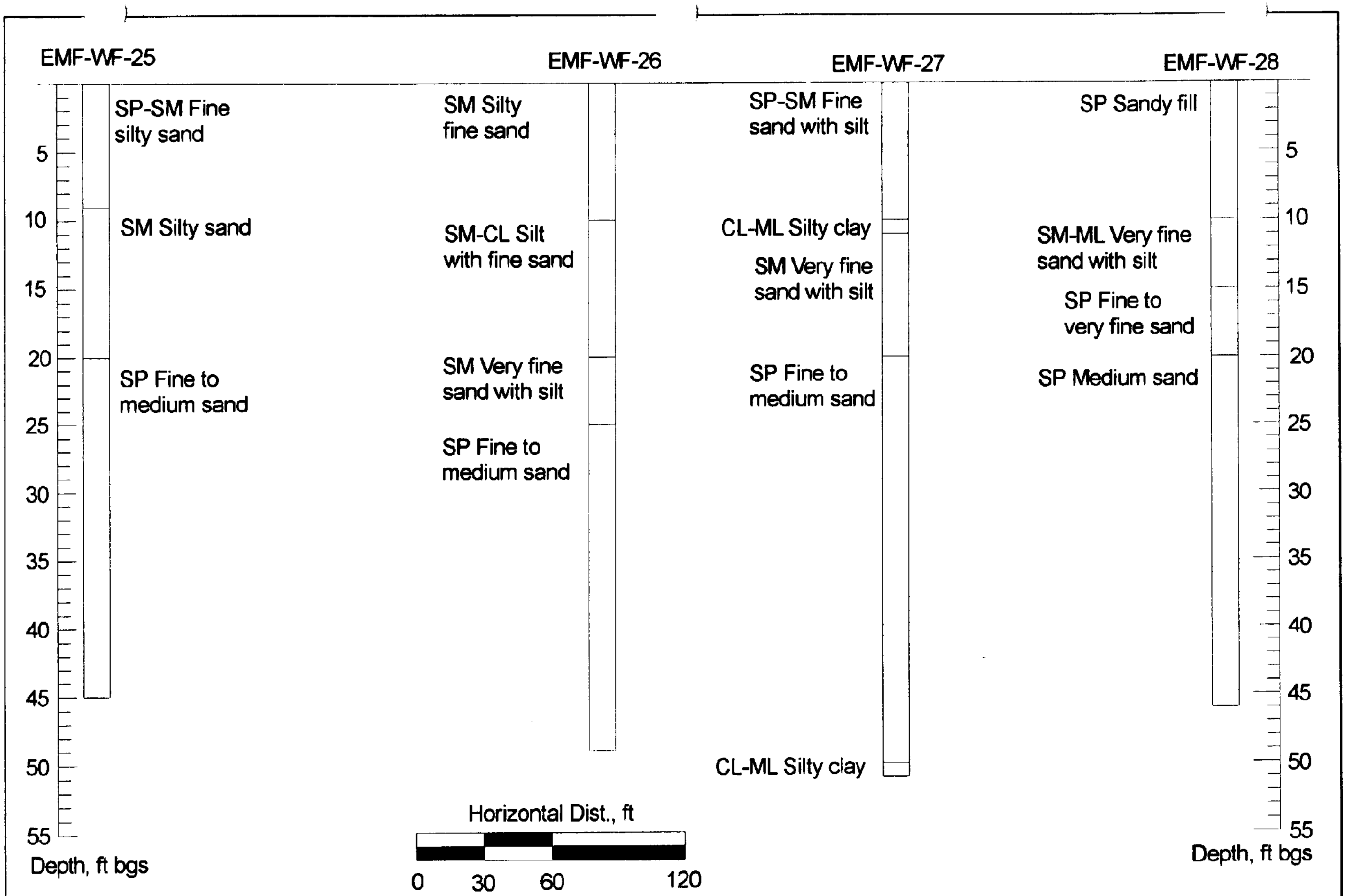


Figure 2-3. Cross Section Showing Stratigraphy in Borings Across West Side of WBF Site.

KCSlip4 44063

SEA410593

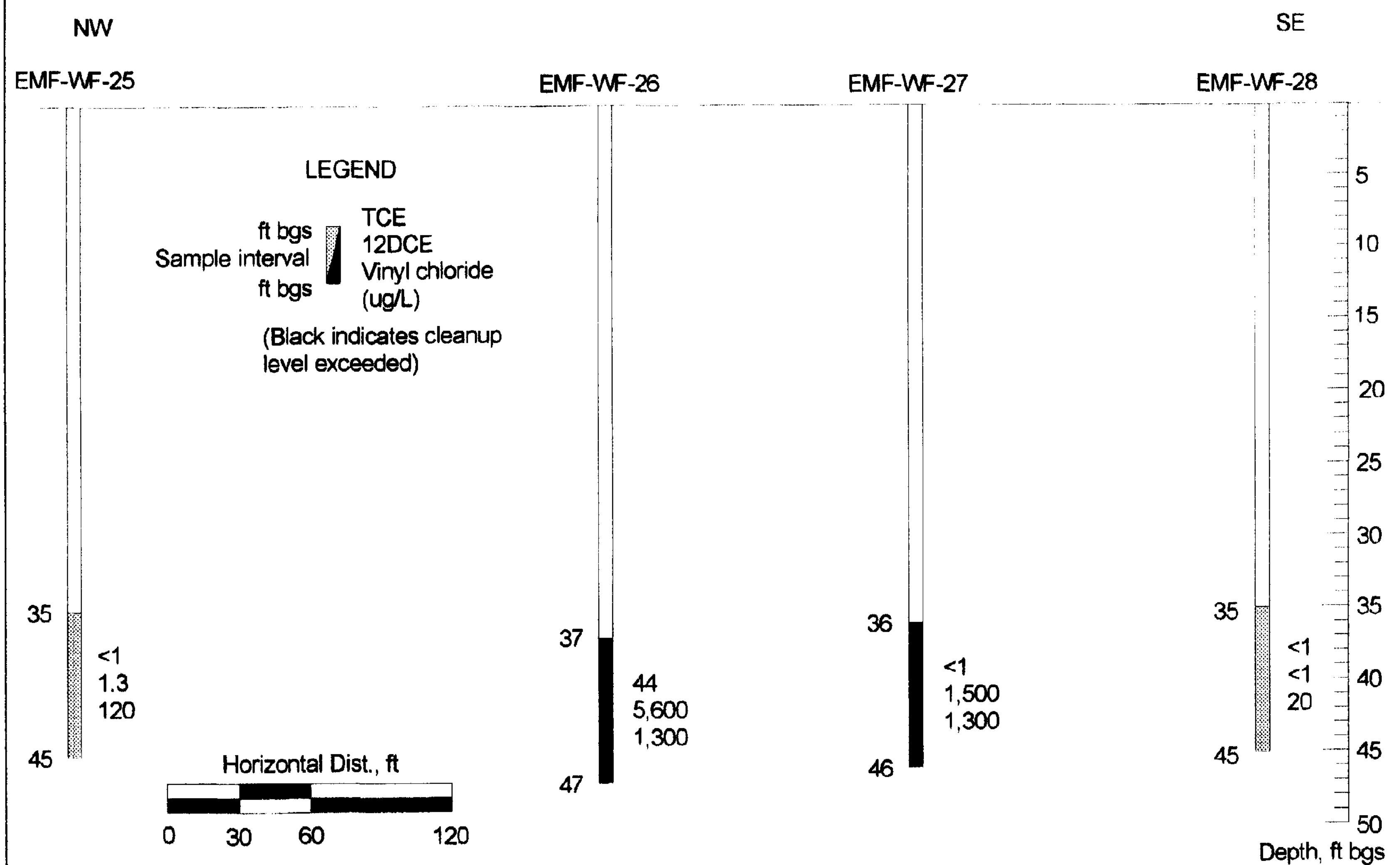
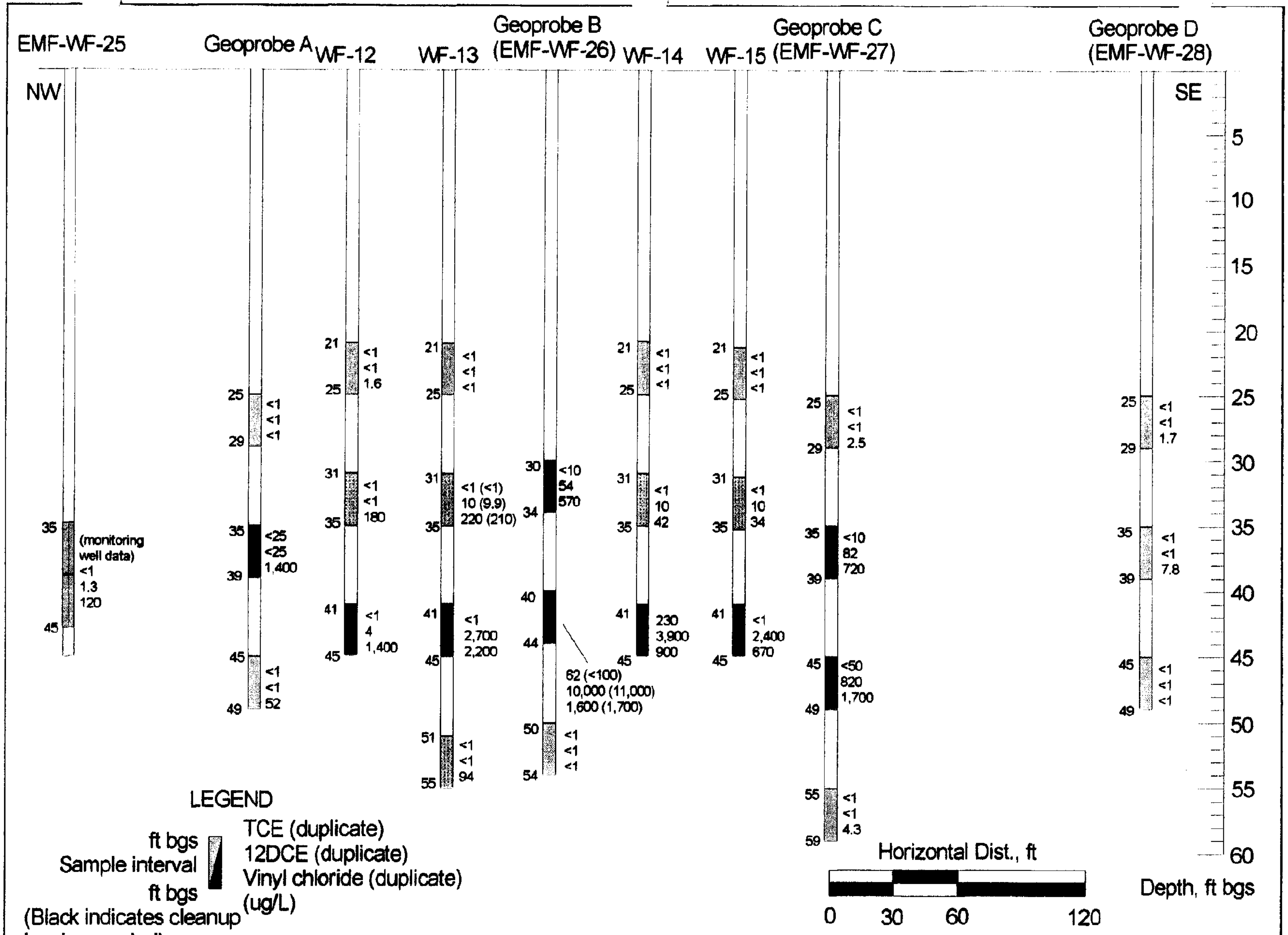


Figure 2-15. Results of Phase III Sampling of Monitoring Wells At Western Boundary.

KCSlip4 44064

SEA410594



Results of Phase III Geoprobe Sampling.

KCSlip4 44065

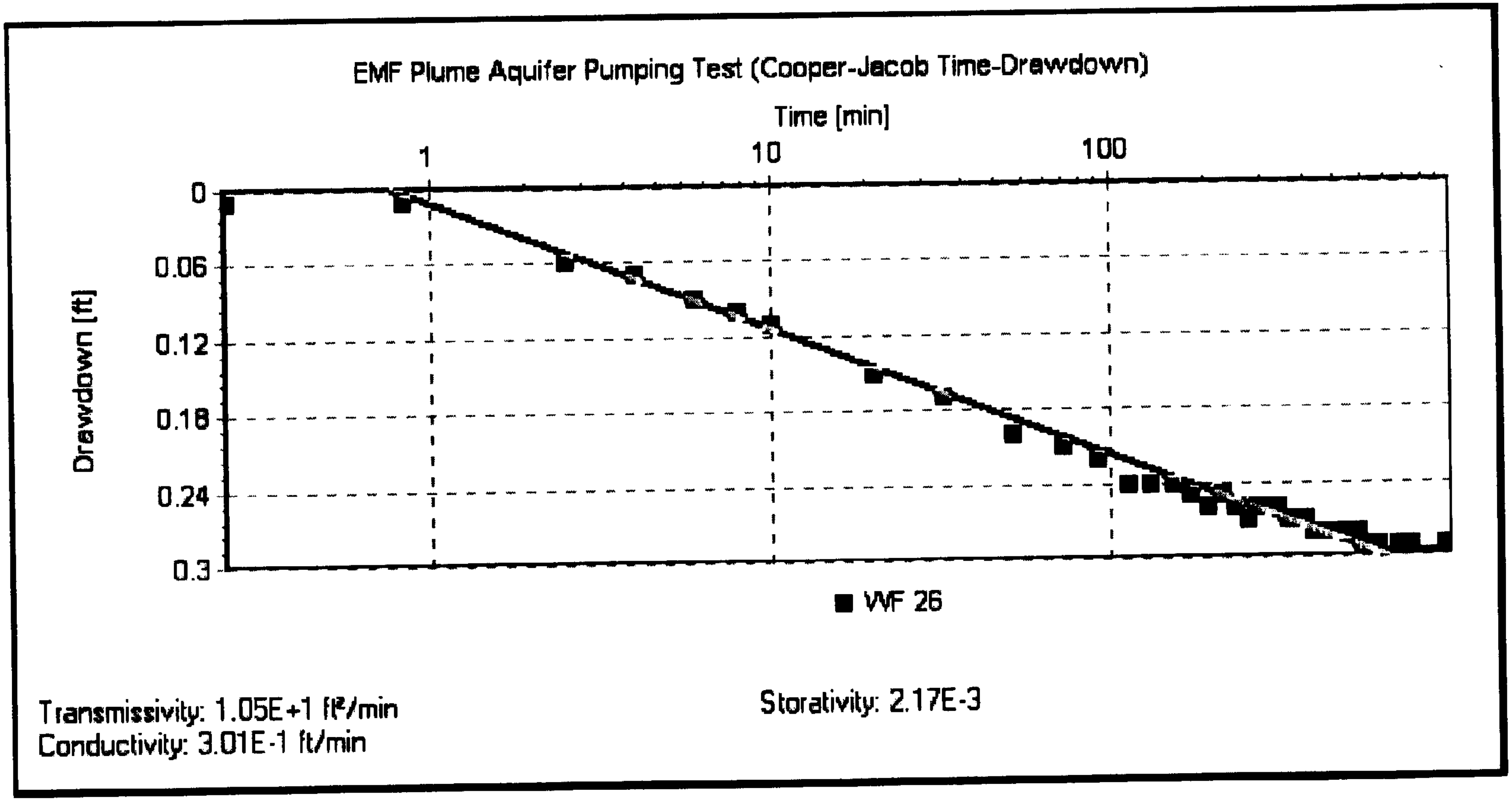
SEA410595

Appendix B

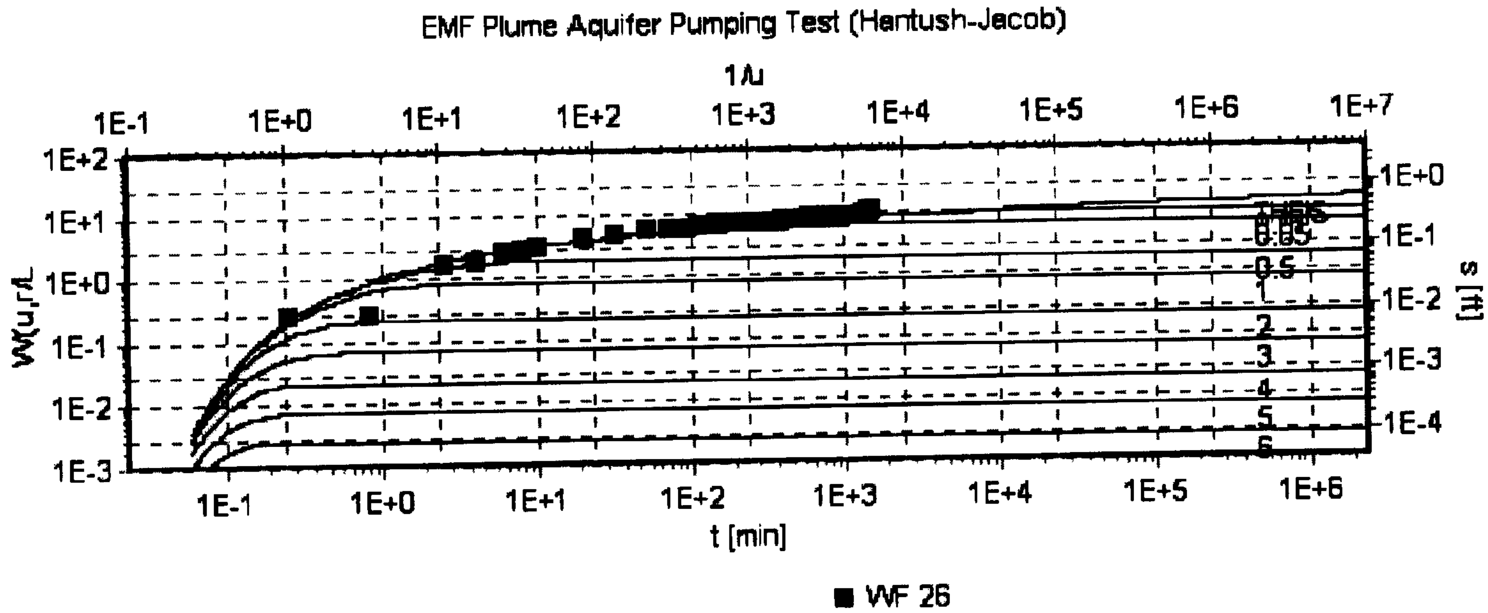
Drawdown Plots/Data Analysis

Pumping Test Data

KCSlip4 44067

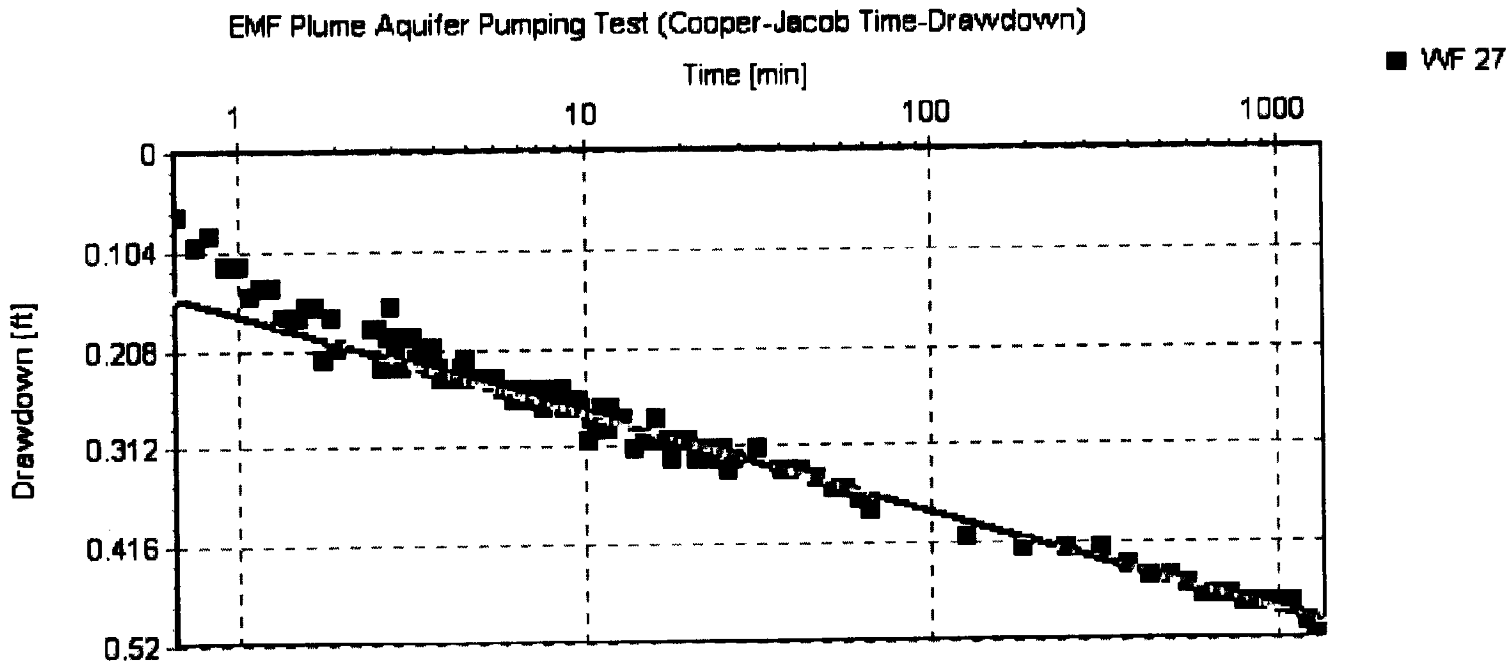


EMF Plume Aquifer Pumping Test (Cooper-Jacob Time-Drawdown)
Time [min]
1
10
100
0
0.06
0.12
0.18
0.24
0.3
Drawdown [ft]
WF 26
Transmissivity: 1.05E+1 ft²/min
Conductivity: 3.01E-1 ft/min
Storativity: 2.17E-3



Transmissivity: 1.30E+1 ft²/min
Conductivity: 3.70E-1 ft/min

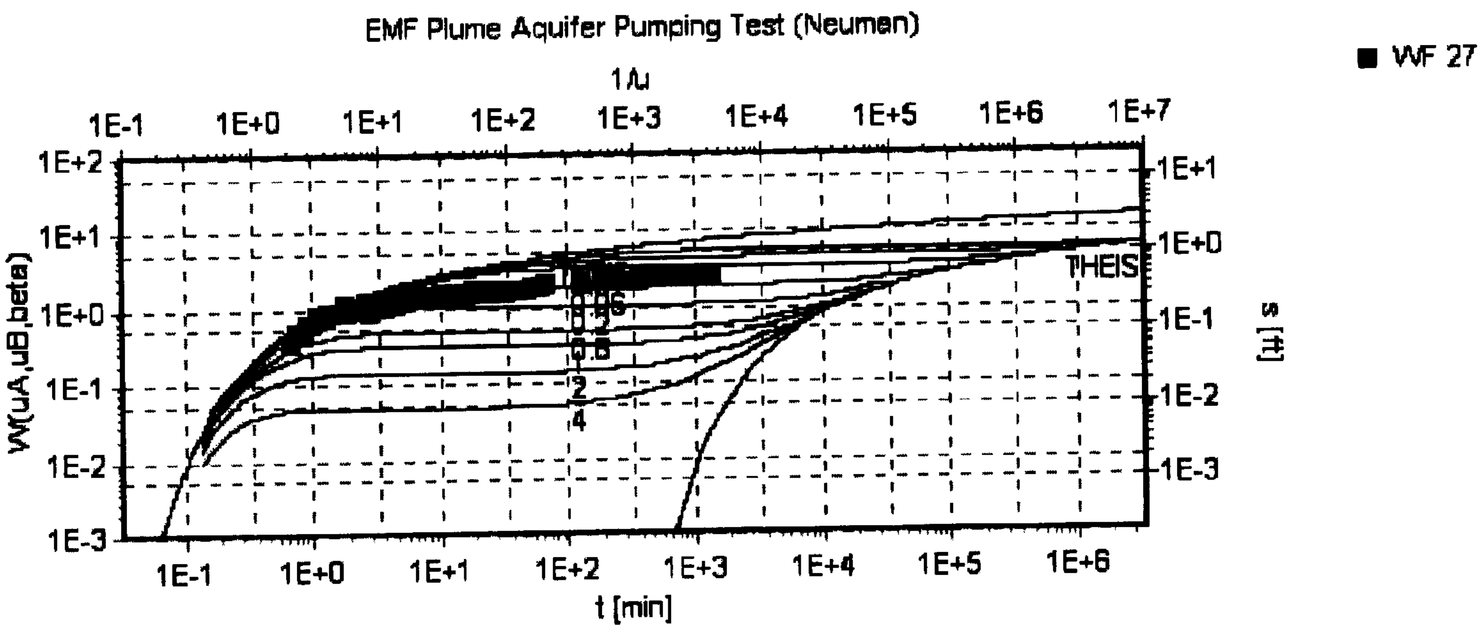
Storativity: 1.43E-3
c: 6.54E+6 min



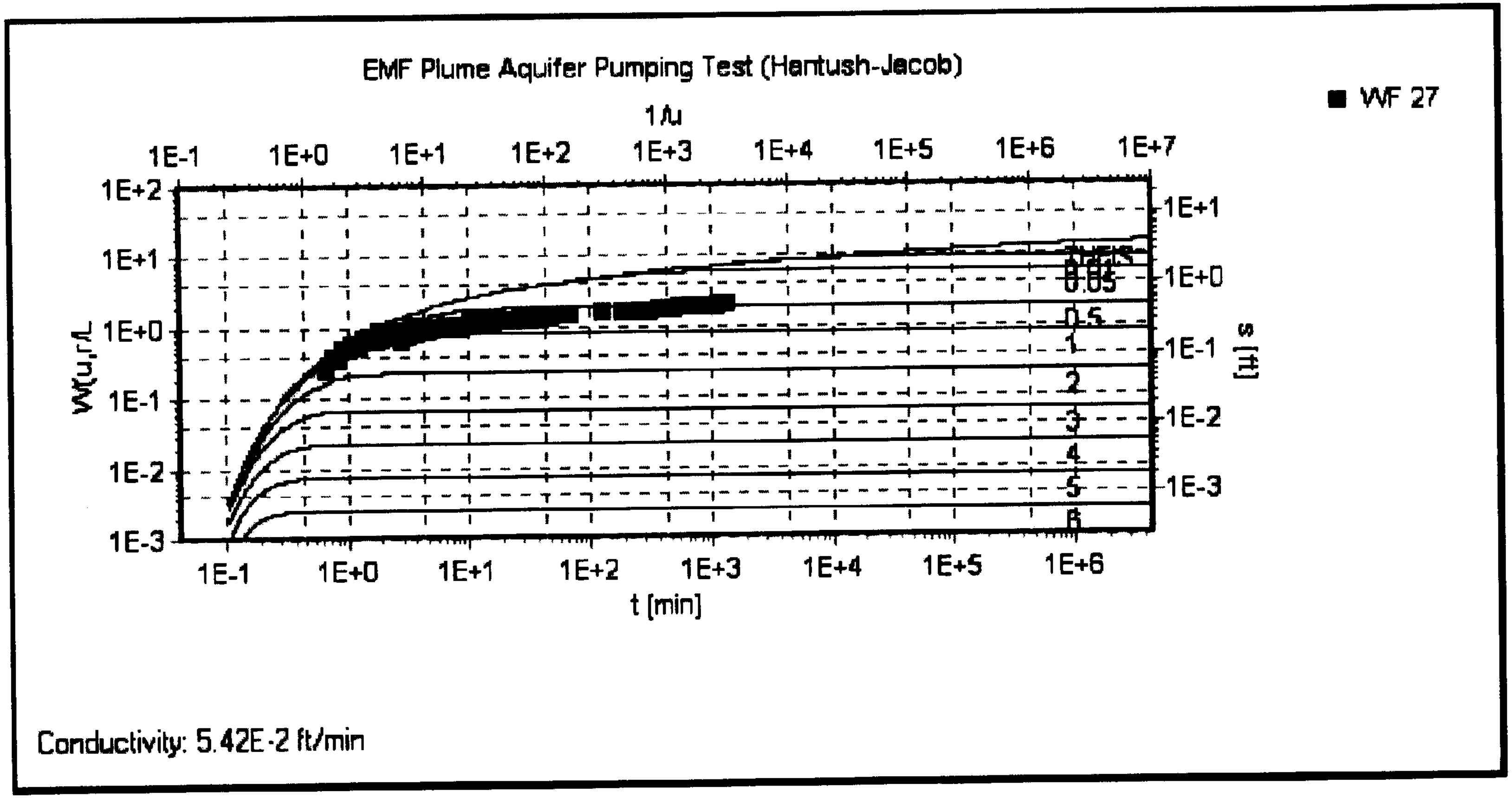
Transmissivity: 1.03E+1 ft²/min
Conductivity: 2.95E-1 ft/min

KCSlip4 44070

SEA410600

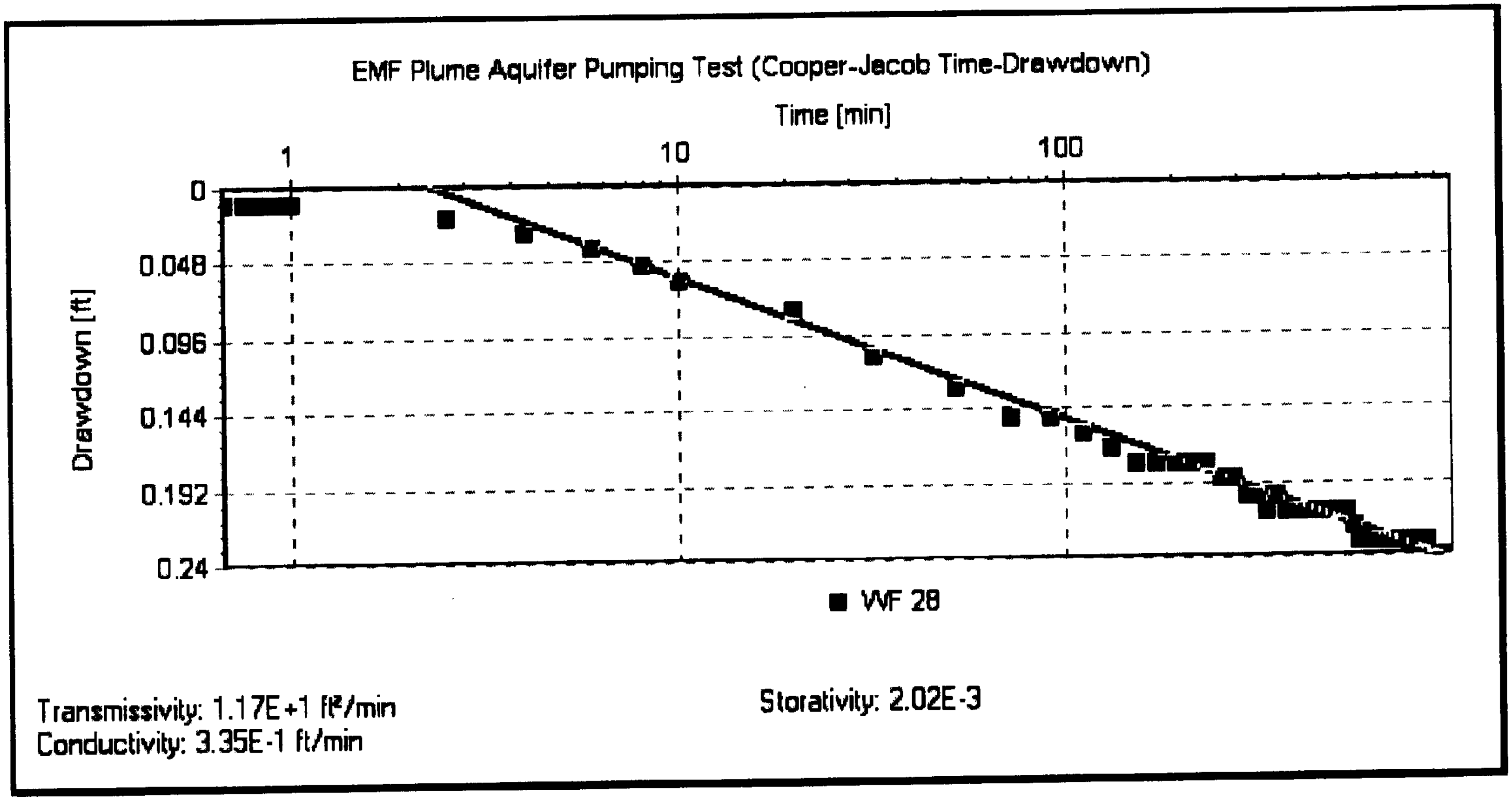


Transmissivity: 2.50E+0 ft²/min
Conductivity: 7.15E-2 ft/min



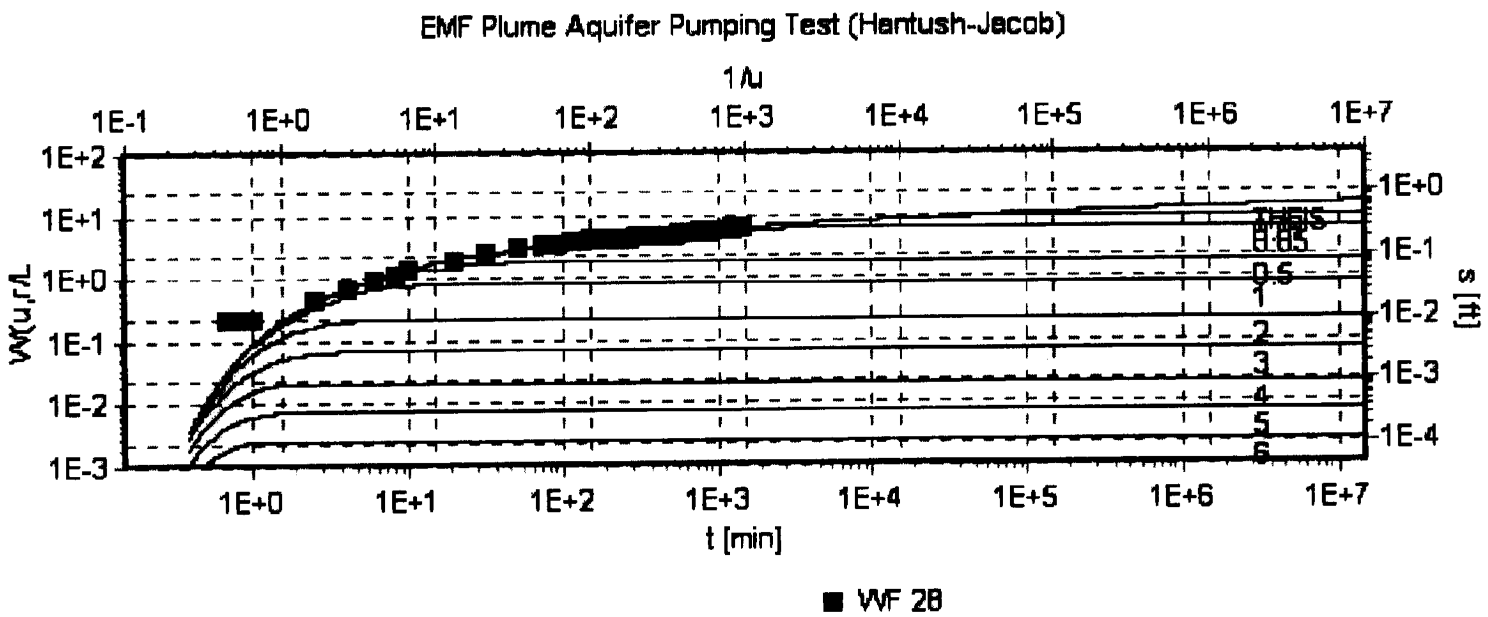
KCSlip4 44072

SEA410602



KCSlip4 44073

SEA410603

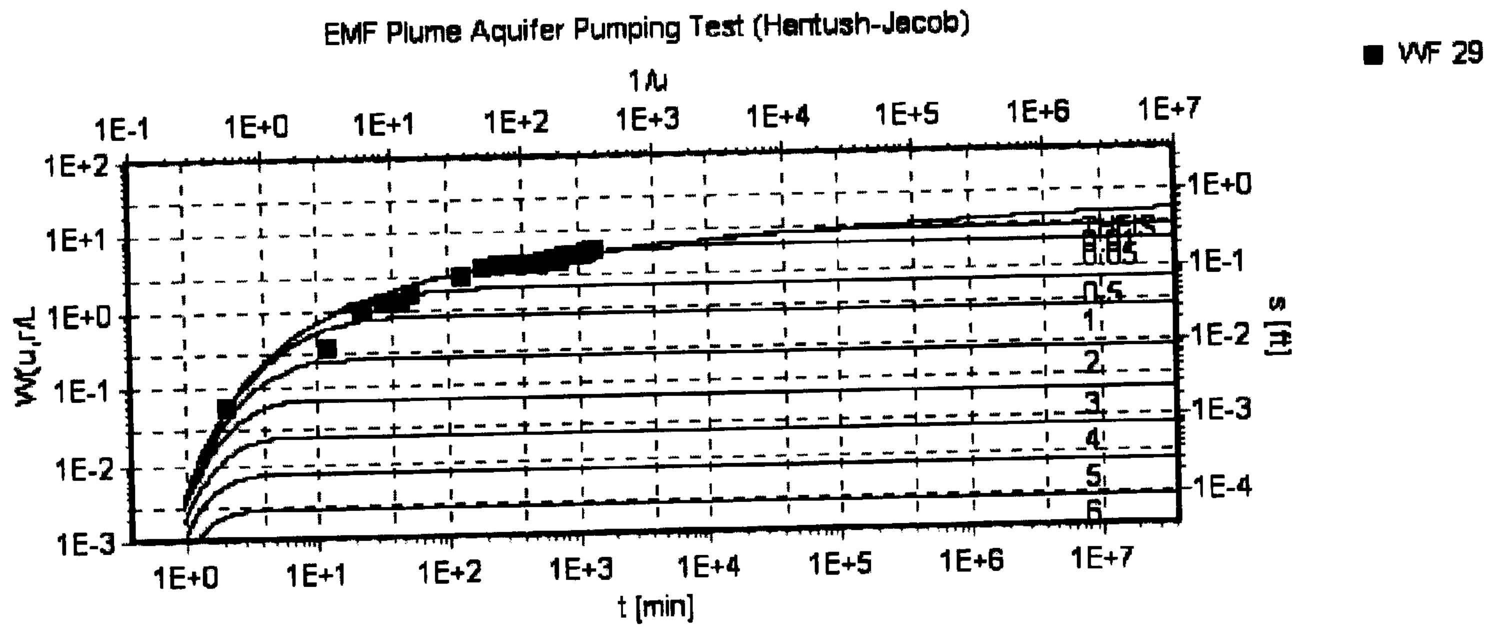


Transmissivity: 1.08E+1 ft²/min
Conductivity: 3.08E-1 ft/min

Storativity: 2.15E-3
c: 2.81E+7 min

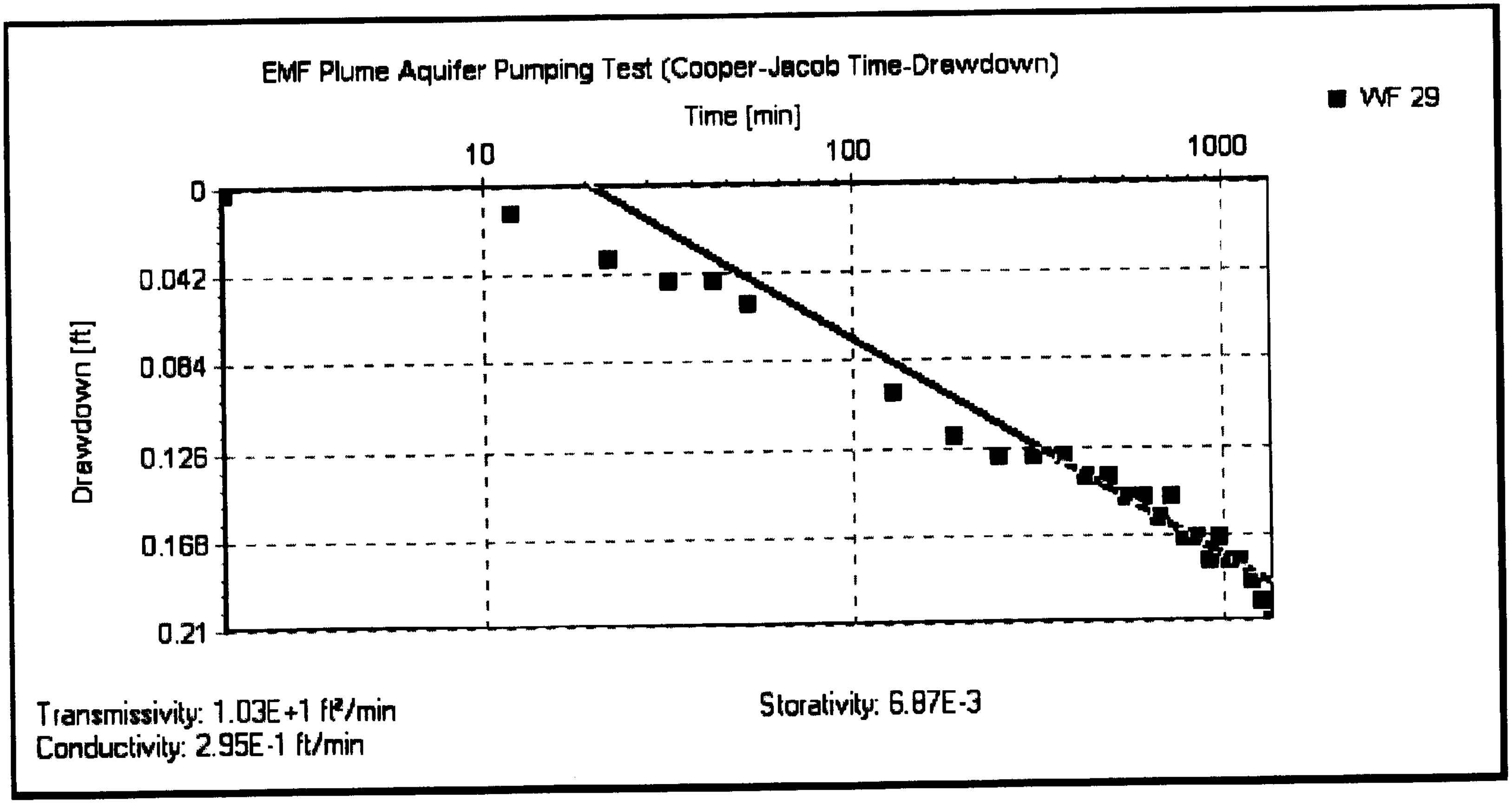
KCSlip4 44074

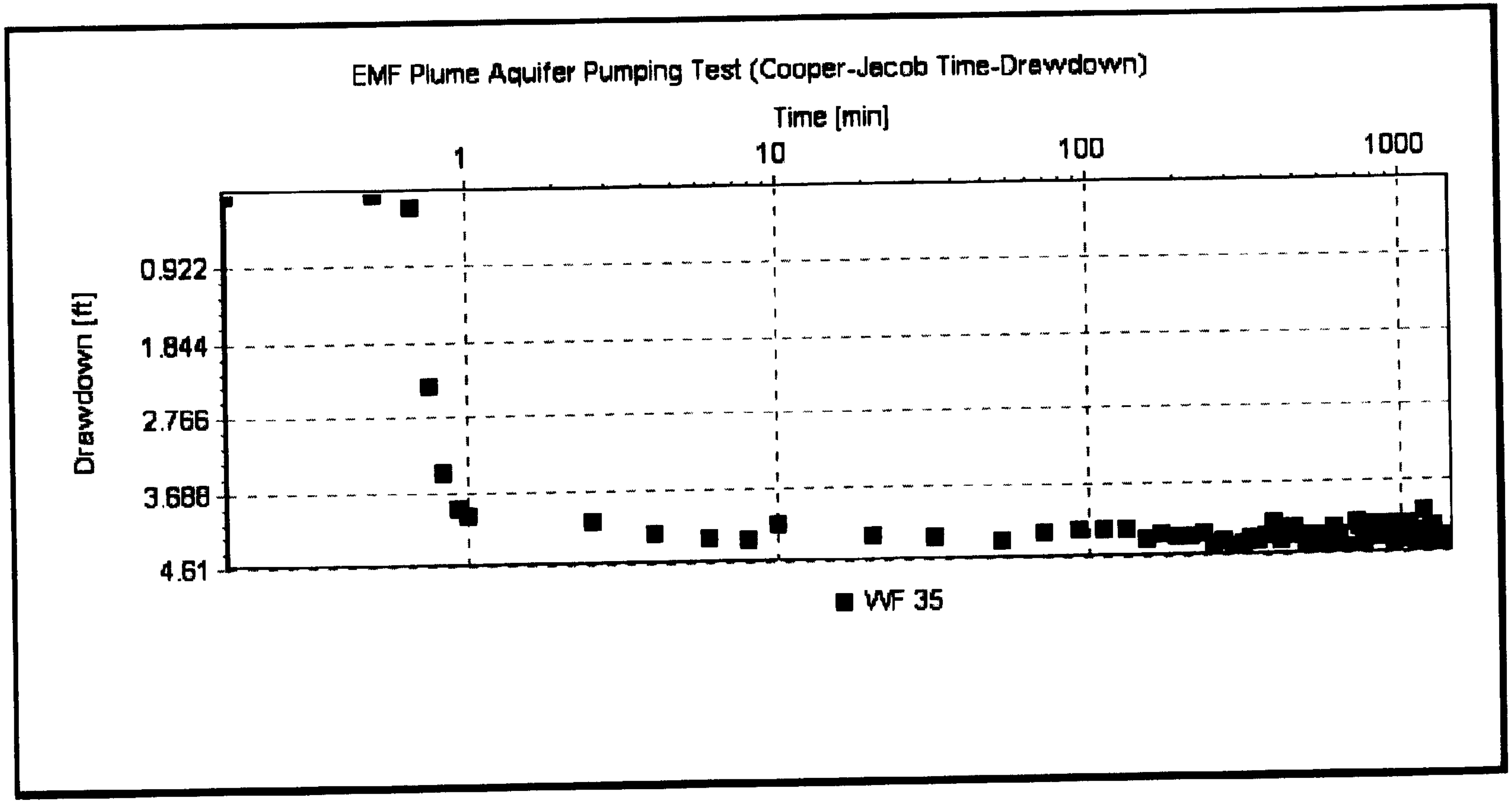
SEA410604



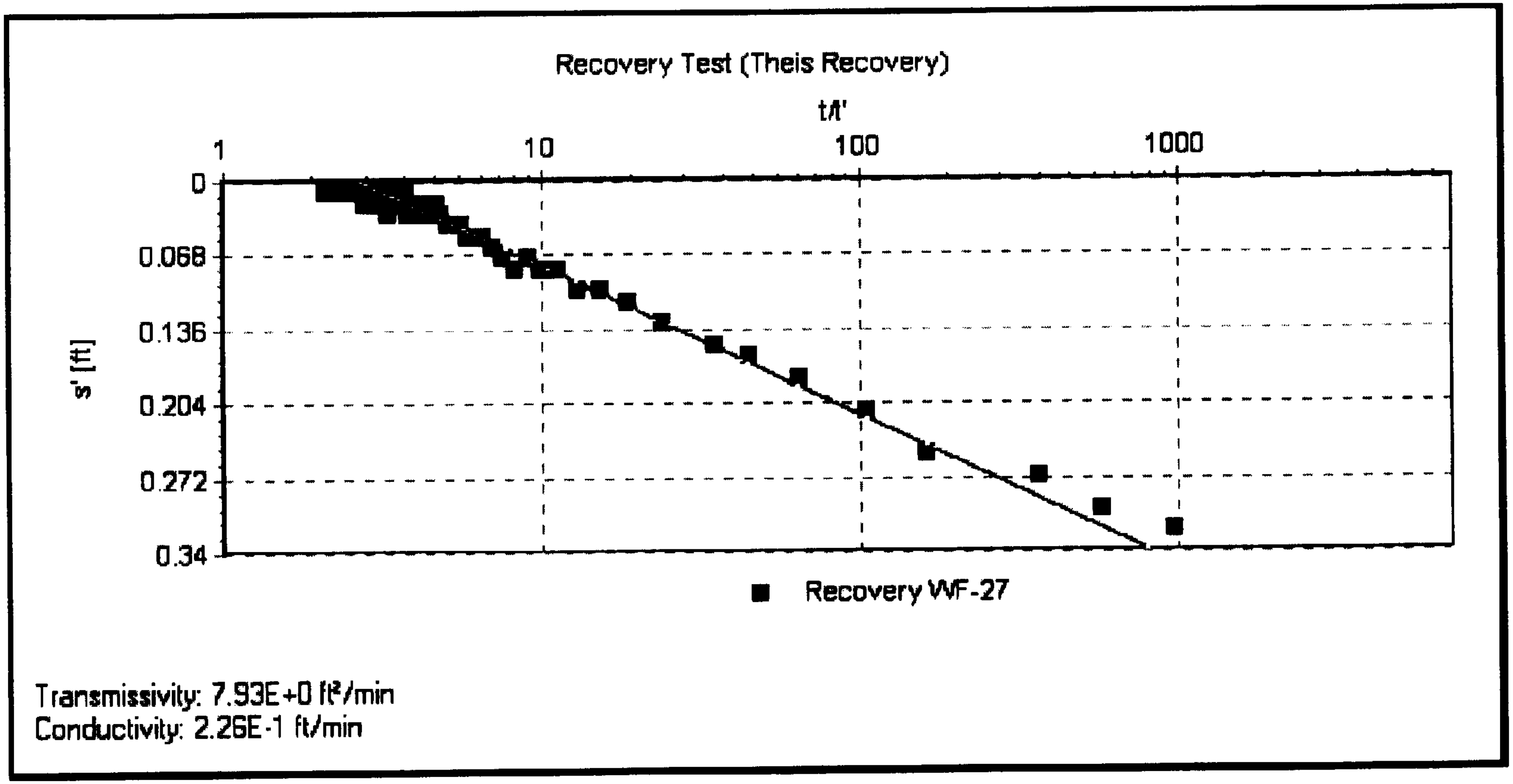
Transmissivity: 1.31E+1 ft²/min
Conductivity: 3.75E-1 ft/min

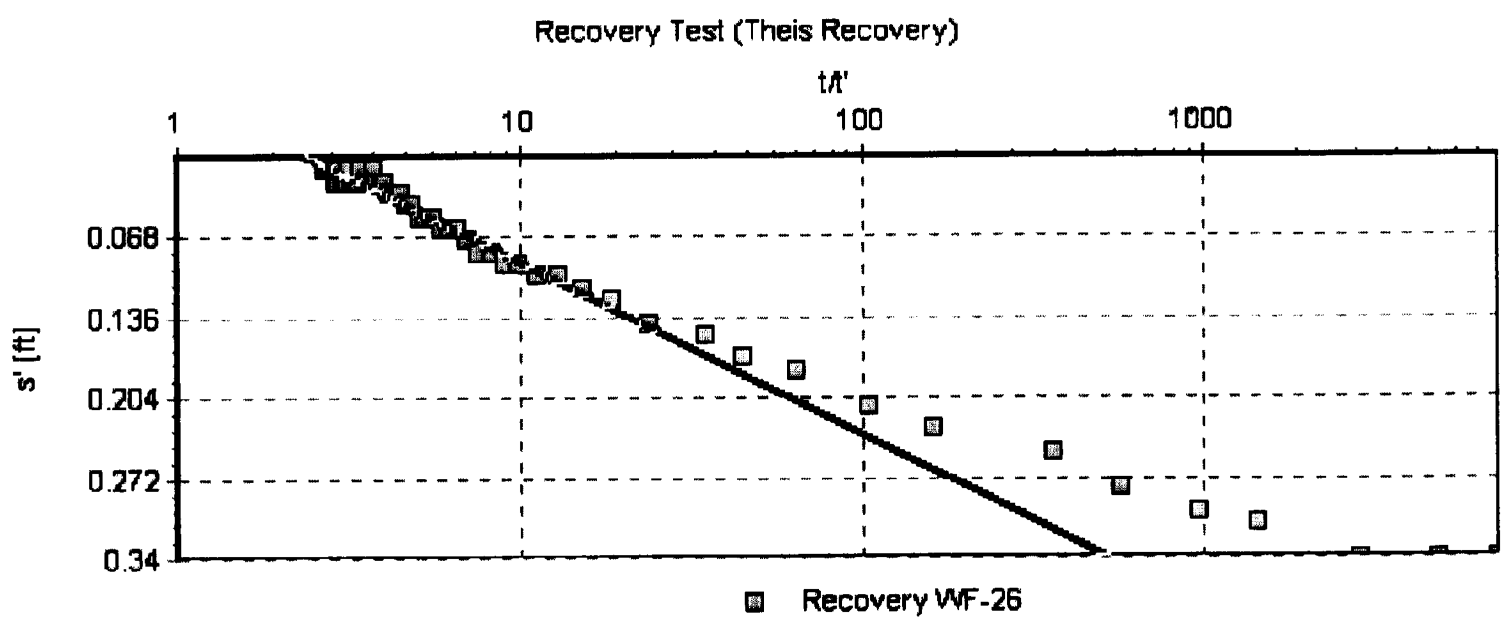
Storativity: 2.98E-3
c: 5.12E+7 min


EMF Plume Aquifer Pumping Test (Cooper-Jacob Time-Drawdown)
Time [min]
10
100
1000
WF 29
Drawdown [ft]
0
0.042
0.084
0.126
0.168
0.21
Transmissivity: 1.03E+1 ft²/min
Conductivity: 2.95E-1 ft/min
Storativity: 6.87E-3

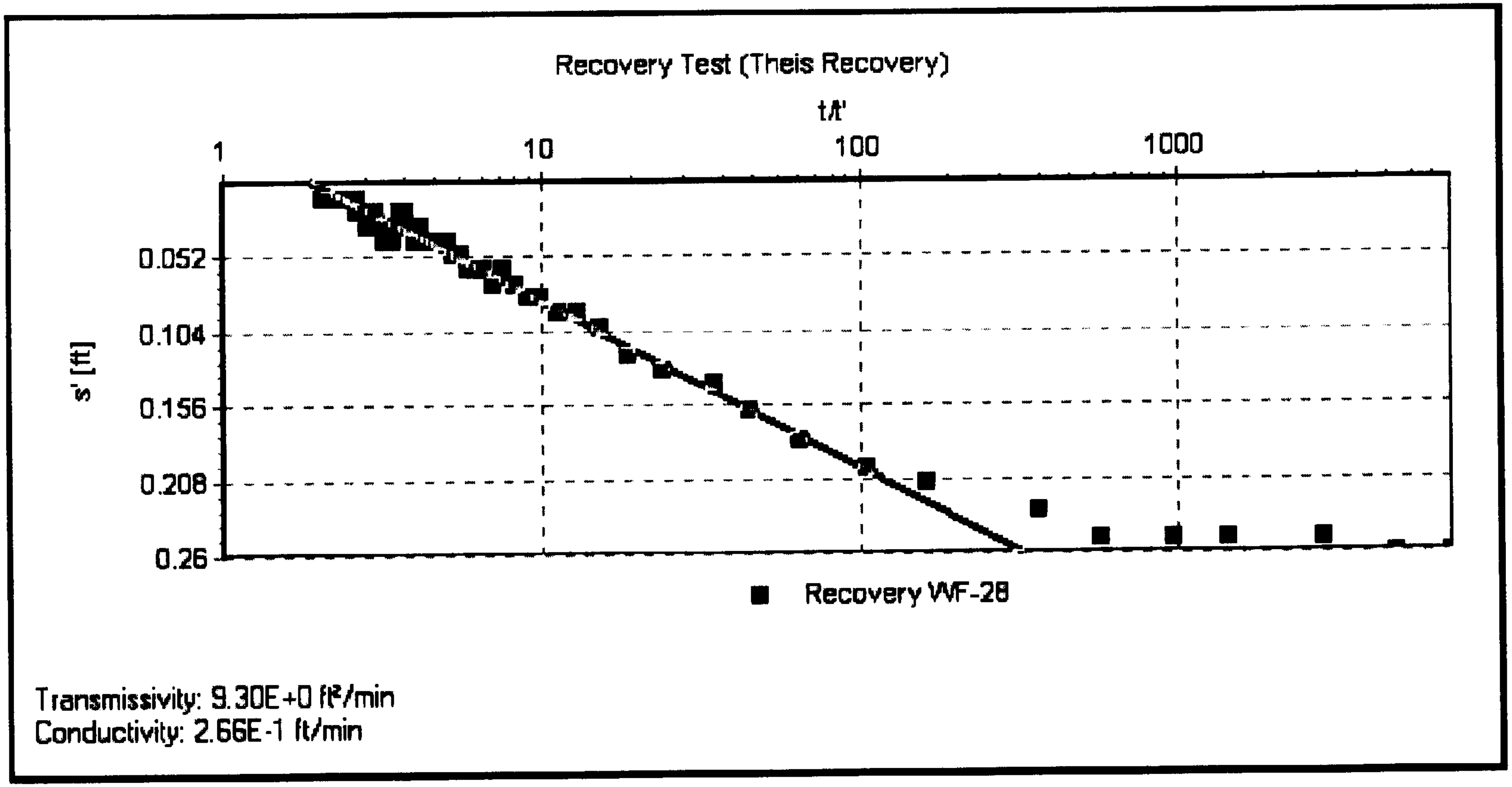

EMF Plume Aquifer Pumping Test (Cooper-Jacob Time-Drawdown)
Time [min]
1
10
100
1000
Drawdown [ft]
0.922
1.844
2.766
3.688
4.61
WF 35

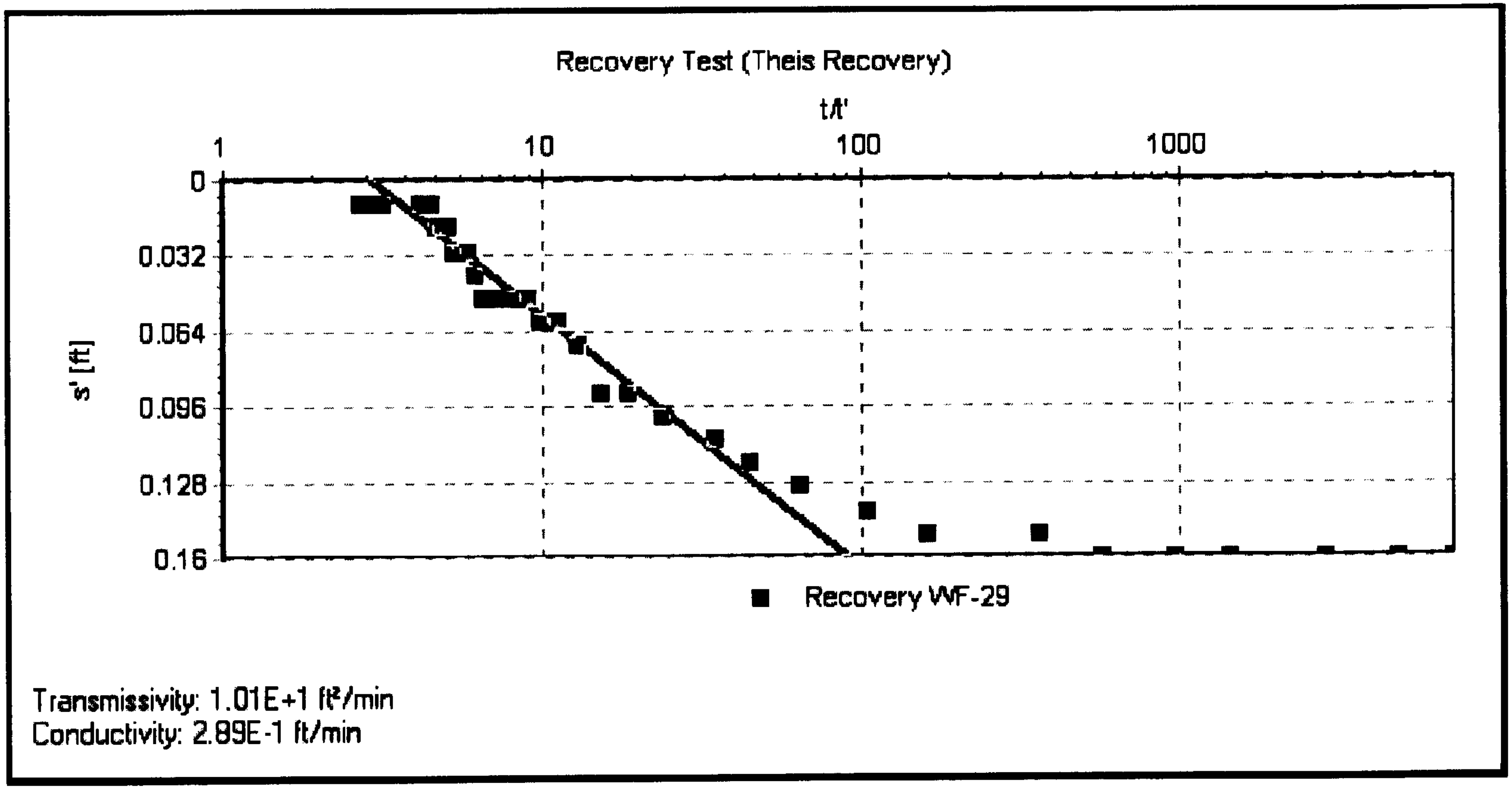
Recovery Test Data


Recovery Test (Theis Recovery)
t/t'
1
10
100
1000
0
0.068
0.136
0.204
0.272
0.34
s' [ft]
Recovery WF-27
Transmissivity: 7.93E+0 ft²/min
Conductivity: 2.26E-1 ft/min



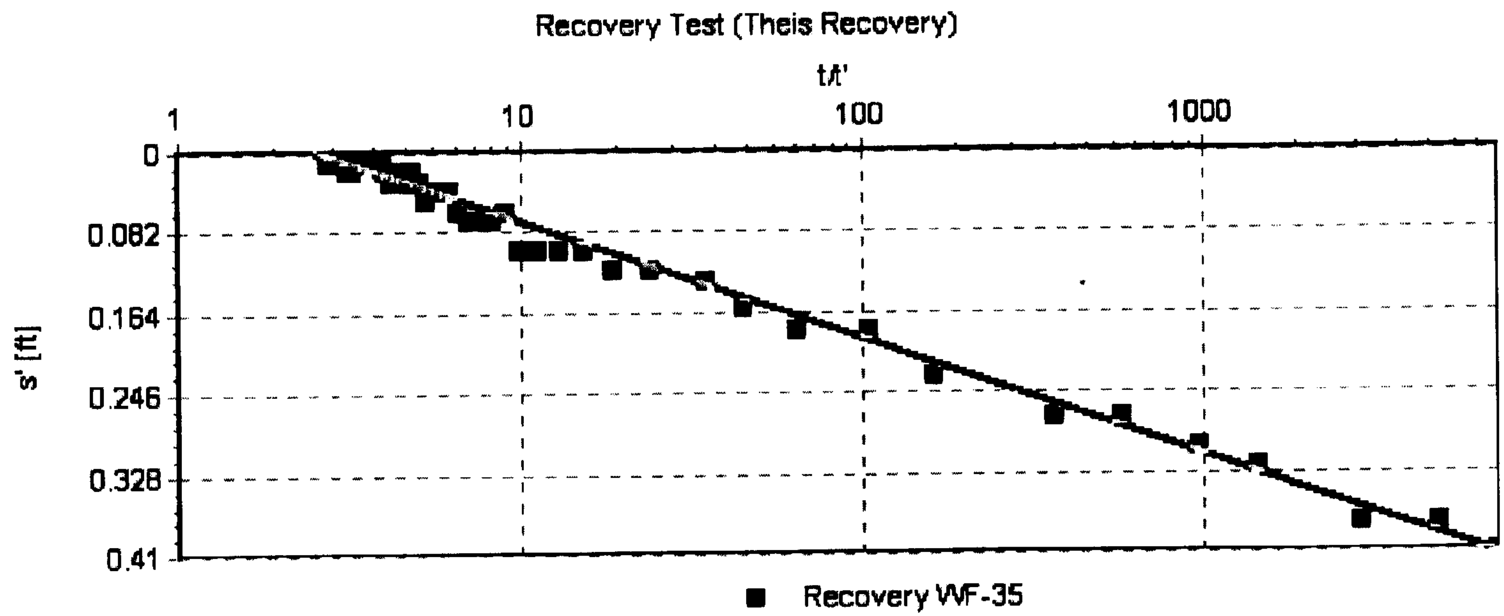
Transmissivity: 7.46E+0 ft²/min
Conductivity: 2.13E-1 ft/min


Recovery Test (Theis Recovery)
t/t'
1
10
100
1000
s' [ft]
0.052
0.104
0.156
0.208
0.26
Recovery WF-28
Transmissivity: 9.30E+0 ft²/min
Conductivity: 2.66E-1 ft/min



KCSlip4 44082

SEA410612



Transmissivity: 9.07E+0 ft²/min
Conductivity: 2.59E-1 ft/min

Appendix C

Time vs. Drawdown Data Tables

Pumping Test Data

		Elapse		s		s		s
Date	Time	Minutes	WF-28	ft	WF-35	ft	WF-26	ft
09/12/01	10:24:00	0.00	7.04	0.00	14.58	0.00	9.58	0.00
09/12/01	10:24:05	0.08	7.05	0.00	14.58	0.00	9.58	0.00
09/12/01	10:24:10	0.17	7.05	0.00	14.56	0.02	9.58	0.00
09/12/01	10:24:15	0.25	7.05	0.00	14.58	0.00	9.57	0.01
09/12/01	10:24:20	0.33	7.04	0.00	14.58	0.00	9.59	0.00
09/12/01	10:24:25	0.42	7.05	0.00	14.58	0.00	9.58	0.00
09/12/01	10:24:30	0.50	7.04	0.00	14.56	0.02	9.58	0.00
09/12/01	10:24:35	0.58	7.05	0.00	14.59	0.00	9.58	0.00
09/12/01	10:24:40	0.67	7.03	0.01	14.40	0.18	9.59	0.00
09/12/01	10:24:45	0.75	7.03	0.01	12.21	2.37	9.58	0.00
09/12/01	10:24:50	0.83	7.03	0.01	11.12	3.46	9.57	0.01
09/12/01	10:24:55	0.92	7.03	0.01	10.69	3.89	9.58	0.00
09/12/01	10:25:00	1	7.03	0.01	10.60	3.98	9.58	0.00
09/12/01	10:26:30	2.5	7.02	0.02	10.51	4.07	9.52	0.06
09/12/01	10:27:50	4	7.01	0.03	10.34	4.24	9.51	0.07
09/12/01	10:30:01	6	7.00	0.04	10.29	4.29	9.49	0.09
09/12/01	10:32:01	8	6.99	0.05	10.25	4.33	9.48	0.10
09/12/01	10:34:01	10	6.98	0.06	10.45	4.13	9.47	0.11
09/12/01	10:43:54	20	6.96	0.08	10.29	4.29	9.43	0.15
09/12/01	10:55:40	32	6.93	0.11	10.24	4.34	9.41	0.17
09/12/01	11:15:40	52	6.91	0.13	10.19	4.39	9.38	0.20
09/12/01	11:35:40	72	6.89	0.15	10.29	4.29	9.37	0.21
09/12/01	11:55:40	92	6.89	0.15	10.30	4.28	9.36	0.22
09/12/01	12:15:52	112	6.88	0.16	10.30	4.28	9.34	0.24
09/12/01	12:35:28	132.0	6.87	0.17	10.32	4.26	9.34	0.24
09/12/01	12:55:28	152	6.86	0.18	10.19	4.39	9.34	0.24
09/12/01	13:15:28	172	6.86	0.18	10.27	4.32	9.33	0.25
09/12/01	13:35:28	192	6.86	0.18	10.21	4.37	9.32	0.26
09/12/01	13:55:28	212	6.86	0.18	10.23	4.35	9.33	0.25
09/12/01	14:15:28	232	6.86	0.18	10.27	4.32	9.32	0.26
09/12/01	14:35:28	252	6.85	0.19	10.12	4.46	9.31	0.27
09/12/01	14:55:28	272	6.85	0.19	10.17	4.41	9.32	0.26
09/12/01	15:15:28	292	6.84	0.20	10.08	4.50	9.32	0.26
09/12/01	15:35:28	312	6.84	0.20	10.14	4.45	9.32	0.26
09/12/01	15:55:28	332	6.83	0.21	10.19	4.39	9.31	0.27
09/12/01	16:15:28	352	6.84	0.20	10.15	4.43	9.31	0.27
09/12/01	16:35:28	372	6.83	0.21	10.21	4.37	9.31	0.27
09/12/01	16:55:28	392	6.83	0.21	10.37	4.21	9.31	0.28
09/12/01	17:15:28	412	6.83	0.21	10.16	4.42	9.31	0.28
09/12/01	17:35:28	432	6.83	0.21	10.32	4.26	9.30	0.28
09/12/01	17:55:28	452	6.83	0.21	10.31	4.27	9.31	0.28
09/12/01	18:15:28	472	6.83	0.21	10.22	4.36	9.31	0.28
09/12/01	18:35:28	492	6.83	0.21	10.11	4.47	9.30	0.28
09/12/01	18:55:28	512	6.83	0.21	10.21	4.37	9.31	0.28
09/12/01	19:15:28	532	6.83	0.21	10.11	4.47	9.30	0.28
09/12/01	19:35:28	552	6.82	0.22	10.21	4.37	9.29	0.29
09/12/01	19:55:28	572	6.81	0.23	10.14	4.45	9.29	0.29
09/12/01	20:15:28	592	6.81	0.23	10.18	4.40	9.28	0.30
09/12/01	20:35:28	612	6.81	0.23	10.30	4.28	9.29	0.29
09/12/01	20:55:28	632	6.81	0.23	10.21	4.37	9.28	0.30
09/12/01	21:15:28	652	6.81	0.23	10.03	4.55	9.28	0.30
09/12/01	21:35:28	672	6.81	0.23	10.05	4.53	9.28	0.30

09/12/01	21:55:28	692	6.81	0.23	10.02	4.56	9.29	0.29
09/12/01	22:15:28	712	6.81	0.23	10.38	4.20	9.29	0.29
09/12/01	22:35:28	732	6.81	0.23	10.32	4.26	9.29	0.29
09/12/01	22:55:28	752	6.81	0.23	10.08	4.50	9.29	0.29
09/12/01	23:15:28	772	6.80	0.24	10.35	4.23	9.28	0.30
09/12/01	23:35:28	792	6.81	0.23	10.29	4.29	9.28	0.30
09/12/01	23:55:28	812	6.80	0.24	10.20	4.38	9.28	0.30
09/13/01	0:15:28	832	6.80	0.24	10.18	4.40	9.28	0.30
09/13/01	0:35:28	852	6.81	0.23	10.36	4.22	9.28	0.30
09/13/01	0:55:28	872	6.80	0.24	10.18	4.40	9.28	0.30
09/13/01	1:15:28	892	6.80	0.24	10.33	4.25	9.28	0.30
09/13/01	1:35:28	912	6.80	0.24	10.30	4.28	9.28	0.30
09/13/01	1:55:28	932	6.80	0.24	10.34	4.24	9.28	0.30
09/13/01	2:15:28	952	6.80	0.24	10.07	4.51	9.29	0.29
09/13/01	2:35:28	972	6.80	0.24	10.23	4.35	9.28	0.30
09/13/01	2:55:28	992	6.80	0.24	10.17	4.41	9.28	0.30
09/13/01	3:15:28	1012	6.80	0.24	10.21	4.37	9.28	0.30
09/13/01	3:35:28	1032	6.80	0.24	10.34	4.24	9.28	0.30
09/13/01	3:55:28	1052	6.80	0.24	10.31	4.27	9.28	0.30
09/13/01	4:15:28	1072	6.80	0.24	10.23	4.35	9.27	0.31
09/13/01	4:35:28	1092	6.80	0.24	10.15	4.43	9.28	0.30
09/13/01	4:55:28	1112	6.80	0.24	10.14	4.45	9.28	0.30
09/13/01	5:15:28	1132	6.80	0.24	10.15	4.43	9.27	0.31
09/13/01	5:35:28	1152	6.79	0.25	10.16	4.42	9.27	0.31
09/13/01	5:55:28	1172	6.79	0.25	10.49	4.09	9.27	0.31
09/13/01	6:15:28	1192	6.79	0.25	10.20	4.38	9.27	0.31
09/13/01	6:35:28	1212	6.79	0.25	10.25	4.33	9.26	0.32
09/13/01	6:55:28	1232	6.78	0.26	10.10	4.48	9.26	0.32
09/13/01	7:15:28	1252	6.77	0.27	10.28	4.30	9.25	0.33
09/13/01	7:35:28	1272	6.77	0.27	10.30	4.28	9.25	0.33
09/13/01	7:55:28	1292	6.77	0.27	10.07	4.51	9.24	0.34
09/13/01	8:15:28	1312	6.77	0.27	10.11	4.47	9.24	0.34
09/13/01	8:35:28	1332	6.76	0.28	10.06	4.52	9.24	0.34
09/13/01	8:55:28	1352	6.76	0.28	10.17	4.41	9.24	0.34
09/13/01	9:15:28	1372	6.75	0.29	10.19	4.39	9.23	0.35
09/13/01	9:35:28	1392	6.75	0.29	10.16	4.42	9.22	0.36
09/13/01	9:55:28	1412	6.75	0.29	10.03	4.55	9.21	0.37
09/13/01	10:15:28	1432	6.75	0.29	10.19	4.39	9.21	0.37
09/13/01	10:29:53	1446	6.75	0.29	9.97	4.61	9.21	0.37
		Elapse		s		s		s
Date	Time	Minutes	WF-28	ft	WF-35	ft	WF-26	ft

Well WF-29

Date and Time	elasped time in minutes	drawdown in feet
9/12/2001 10:24		0
9/12/2001 10:26	2	0.002
9/12/2001 10:36	12	0.012
9/12/2001 10:46	22	0.034
9/12/2001 10:56	32	0.045
9/12/2001 11:06	42	0.045
9/12/2001 11:16	52	0.056
9/12/2001 12:33	129	0.1
9/12/2001 13:30	186	0.12
9/12/2001 14:33	249	0.13
9/12/2001 15:33	309	0.13
9/12/2001 16:33	369	0.13
9/12/2001 17:33	429	0.14
9/12/2001 18:33	489	0.14
9/12/2001 19:33	549	0.15
9/12/2001 20:33	609	0.15
9/12/2001 21:34	670	0.16
9/12/2001 22:32	728	0.15
9/12/2001 23:33	789	0.17
9/13/2001 0:36	852	0.17
9/13/2001 1:45	921	0.18
9/13/2001 2:34	970	0.17
9/13/2001 3:39	1035	0.18
9/13/2001 4:44	1100	0.18
9/13/2001 6:15	1191	0.19
9/13/2001 7:39	1275	0.2
9/13/2001 8:54	1350	0.21

Well WF-27

elasped time in minutes	adjusted DD in feet
0.00	0.00
0.09	0.00
0.17	0.00
0.25	0.00
0.34	0.00
0.42	0.00
0.50	0.00
0.59	0.00
0.67	0.07
0.75	0.10
0.84	0.09
0.92	0.12
1.00	0.12
1.08	0.15
1.17	0.14
1.25	0.14
1.33	0.17
1.42	0.17
1.50	0.17
1.58	0.16
1.66	0.16
1.75	0.22
1.83	0.17
1.91	0.21
2.41	0.19
2.49	0.19
2.58	0.23
2.66	0.20
2.74	0.16
2.82	0.21
2.91	0.23
2.99	0.20
3.07	0.20
3.16	0.20
3.24	0.22
3.32	0.22
3.41	0.21
3.49	0.22
3.57	0.23
3.65	0.21
3.74	0.23
3.82	0.24
4.29	0.24
4.38	0.23
4.51	0.22
4.75	0.24
5.00	0.24
5.25	0.24
5.50	0.24
5.74	0.25
5.99	0.25
6.24	0.26

6.49	0.25
6.74	0.25
6.99	0.26
7.24	0.25
7.49	0.27
7.74	0.26
7.98	0.25
8.23	0.26
8.48	0.25
8.73	0.27
8.98	0.27
9.23	0.27
9.48	0.26
9.73	0.27
10.47	0.28
10.72	0.29
10.97	0.28
11.22	0.27
11.47	0.29
11.72	0.27
11.97	0.28
12.21	0.28
12.85	0.28
13.84	0.32
14.84	0.30
15.83	0.28
16.83	0.30
17.82	0.33
18.82	0.30
19.81	0.30
20.81	0.33
21.80	0.32
22.80	0.33
23.79	0.32
24.79	0.32
25.79	0.34
26.55	0.33
31.53	0.32
36.50	0.34
41.48	0.34
46.46	0.35
51.43	0.36
56.41	0.36
61.39	0.37
66.36	0.38
125.00	0.41
183.00	0.42
245.00	0.42
305.00	0.42
365.00	0.44
425.00	0.45
485.00	0.45
545.00	0.46
605.00	0.47

666.00	0.47
724.00	0.47
785.00	0.48
848.00	0.48
917.00	0.48
966.00	0.48
1031.00	0.48
1094.00	0.48
1197.00	0.50
1271.00	0.51
1343.00	0.52
1271.00	0.51
1343.00	0.52

Recovery Test Data

EMF WF Pump test

Date	Time	Well WF-28 DBW* ft	s'	Well WF-27 DBW ft	s'	Well WF-35 DBW ft	s'	Well WF-26 DBW ft	s'	Well WF-29 DBW ft	s'	Mininutes from start
09/13/01	10:29:58	6.75	0.00	13.36	0.00	10.23	0.00	9.21	0.00	15.28	0.00	0.0
09/13/01	10:30:08	6.76	0.01	13.58	0.22	14.13	3.90	9.21	0.00	15.28	0.00	0.2
09/13/01	10:30:18	6.76	0.01	13.62	0.26	14.16	3.93	9.21	0.00	15.28	0.00	0.3
09/13/01	10:30:28	6.77	0.03	13.63	0.27	14.16	3.93	9.21	0.00	15.28	0.00	0.5
09/13/01	10:30:58	6.77	0.02	13.67	0.30	14.22	3.98	9.24	0.03	15.28	0.00	1.0
09/13/01	10:31:28	6.77	0.02	13.70	0.34	14.24	4.01	9.25	0.04	15.28	0.00	1.5
09/13/01	10:32:24	6.77	0.02	13.72	0.36	14.27	4.04	9.27	0.06	15.28	0.00	2.5
09/13/01	10:34:08	6.79	0.04	13.75	0.39	14.27	4.04	9.30	0.09	15.29	0.01	4
09/13/01	10:39:18	6.81	0.06	13.77	0.41	14.32	4.08	9.32	0.11	15.29	0.01	9
09/13/01	10:44:05	6.82	0.07	13.81	0.44	14.36	4.13	9.34	0.13	15.30	0.02	14
09/13/01	10:52:36	6.84	0.09	13.84	0.48	14.36	4.13	9.37	0.16	15.31	0.03	23
09/13/01	11:02:36	6.87	0.12	13.86	0.50	14.38	4.15	9.38	0.17	15.32	0.04	33
09/13/01	11:12:36	6.88	0.13	13.87	0.51	14.41	4.18	9.40	0.19	15.33	0.05	43
09/13/01	11:32:36	6.89	0.14	13.89	0.53	14.42	4.19	9.41	0.20	15.34	0.06	63
09/13/01	11:52:36	6.90	0.15	13.91	0.55	14.42	4.19	9.43	0.22	15.35	0.07	83
09/13/01	12:12:36	6.92	0.17	13.93	0.56	14.45	4.21	9.44	0.23	15.35	0.07	103
09/13/01	12:32:36	6.93	0.18	13.93	0.56	14.45	4.21	9.45	0.24	15.37	0.09	123
09/13/01	12:52:36	6.93	0.18	13.94	0.57	14.45	4.21	9.45	0.24	15.38	0.10	143
09/13/01	13:12:36	6.94	0.19	13.94	0.57	14.45	4.21	9.46	0.25	15.38	0.10	163
09/13/01	13:32:36	6.94	0.19	13.95	0.58	14.48	4.24	9.46	0.25	15.39	0.11	183
09/13/01	13:52:36	6.95	0.20	13.94	0.57	14.47	4.23	9.47	0.26	15.39	0.11	203
09/13/01	14:12:36	6.96	0.21	13.95	0.58	14.47	4.23	9.47	0.26	15.39	0.11	223
09/13/01	14:32:36	6.95	0.20	13.96	0.60	14.47	4.23	9.48	0.27	15.39	0.11	243
09/13/01	14:52:36	6.96	0.21	13.97	0.61	14.48	4.24	9.49	0.28	15.39	0.11	263
09/13/01	15:12:36	6.96	0.21	13.97	0.61	14.50	4.27	9.49	0.28	15.40	0.12	283
09/13/01	15:32:36	6.96	0.21	13.97	0.61	14.50	4.27	9.49	0.28	15.41	0.13	303
09/13/01	15:52:36	6.97	0.22	13.98	0.62	14.50	4.27	9.50	0.29	15.41	0.13	323
09/13/01	16:12:36	6.97	0.22	13.98	0.62	14.49	4.26	9.50	0.29	15.41	0.13	343
09/13/01	16:32:36	6.98	0.23	13.98	0.62	14.51	4.28	9.50	0.29	15.42	0.14	363
09/13/01	16:52:36	6.98	0.23	13.99	0.63	14.52	4.29	9.51	0.30	15.42	0.14	383
09/13/01	17:12:36	6.98	0.23	14.00	0.64	14.51	4.28	9.51	0.30	15.42	0.14	403
09/13/01	17:32:36	6.98	0.23	13.99	0.63	14.51	4.28	9.52	0.31	15.43	0.15	423
09/13/01	17:52:36	6.98	0.23	13.99	0.63	14.52	4.29	9.52	0.31	15.43	0.15	443
09/13/01	18:12:36	6.99	0.24	14.00	0.64	14.51	4.28	9.52	0.31	15.43	0.15	463
09/13/01	18:32:36	6.98	0.23	14.00	0.64	14.52	4.29	9.53	0.32	15.44	0.16	483
09/13/01	18:52:36	6.99	0.24	14.00	0.64	14.53	4.30	9.53	0.32	15.44	0.16	503
09/13/01	19:12:36	6.99	0.24	13.99	0.63	14.54	4.31	9.53	0.32	15.44	0.16	523
09/13/01	19:32:36	7.00	0.25	14.01	0.65	14.54	4.31	9.54	0.33	15.44	0.16	543
09/13/01	19:52:36	7.00	0.25	14.00	0.64	14.53	4.30	9.53	0.32	15.44	0.16	563
09/13/01	20:12:36	6.99	0.24	14.01	0.65	14.54	4.31	9.53	0.32	15.45	0.17	583
09/13/01	20:32:36	6.98	0.23	14.01	0.65	14.54	4.31	9.54	0.33	15.45	0.17	603
09/13/01	20:52:36	6.99	0.24	14.00	0.64	14.54	4.31	9.53	0.32	15.44	0.16	623
09/13/01	21:12:36	6.99	0.24	13.99	0.63	14.53	4.30	9.53	0.32	15.44	0.16	643
09/13/01	21:32:36	6.98	0.23	14.00	0.64	14.52	4.29	9.53	0.32	15.44	0.16	663
09/13/01	21:52:36	6.99	0.24	14.01	0.65	14.52	4.29	9.54	0.33	15.43	0.15	683
09/13/01	22:12:36	6.99	0.24	14.00	0.64	14.52	4.29	9.53	0.32	15.44	0.16	703
09/13/01	22:32:36	6.99	0.24	14.00	0.64	14.54	4.31	9.53	0.32	15.43	0.15	723
09/13/01	22:52:36	7.00	0.25	14.01	0.65	14.54	4.31	9.54	0.33	15.44	0.16	743
09/13/01	23:12:36	6.99	0.24	14.01	0.65	14.53	4.30	9.53	0.32	15.43	0.15	763

Date	Time	Well WF-28 DBW* ft	s'	Well WF-27 DBW ft	s'	Well WF-35 DBW ft	s'	Well WF-26 DBW ft	s'	Well WF-29 DBW ft	s'	Mininutes from start
09/13/01	23:32:36	6.99	0.24	14.00	0.64	14.54	4.31	9.53	0.32	15.44	0.16	783
09/13/01	23:52:36	7.00	0.25	14.00	0.64	14.53	4.30	9.54	0.33	15.44	0.16	803
09/14/01	0:12:36	7.00	0.25	14.00	0.64	14.53	4.30	9.54	0.33	15.45	0.17	823
09/14/01	0:32:36	7.00	0.25	14.01	0.65	14.53	4.30	9.54	0.33	15.44	0.16	843
09/14/01	0:52:36	7.00	0.25	14.01	0.65	14.55	4.32	9.54	0.33	15.43	0.15	863
09/14/01	1:12:36	7.01	0.26	14.02	0.66	14.55	4.32	9.55	0.34	15.44	0.16	883
09/14/01	1:32:36	7.00	0.25	14.02	0.66	14.55	4.32	9.55	0.34	15.44	0.16	903
09/14/01	1:52:36	7.01	0.26	14.01	0.65	14.55	4.32	9.55	0.34	15.45	0.17	923
09/14/01	2:12:36	7.01	0.26	14.02	0.66	14.55	4.32	9.55	0.34	15.45	0.17	943
09/14/01	2:32:36	7.01	0.26	14.01	0.65	14.55	4.32	9.56	0.35	15.45	0.17	963
09/14/01	2:52:36	7.02	0.27	14.02	0.66	14.55	4.32	9.56	0.35	15.46	0.18	983
09/14/01	3:12:36	7.02	0.27	14.02	0.66	14.56	4.33	9.56	0.35	15.45	0.17	1003
09/14/01	3:32:36	7.01	0.26	14.01	0.65	14.55	4.32	9.56	0.35	15.44	0.16	1023
09/14/01	3:52:36	7.01	0.26	14.02	0.66	14.56	4.33	9.57	0.36	15.46	0.18	1043
09/14/01	4:12:36	7.02	0.27	14.02	0.66	14.55	4.32	9.56	0.35	15.45	0.17	1063
09/14/01	4:32:36	7.02	0.27	14.03	0.67	14.56	4.33	9.57	0.36	15.46	0.18	1083
09/14/01	4:52:36	7.01	0.26	14.03	0.67	14.58	4.34	9.58	0.37	15.46	0.18	1103
09/14/01	5:12:36	7.02	0.27	14.06	0.69	14.56	4.33	9.58	0.37	15.45	0.17	1123
09/14/01	5:32:36	7.02	0.27	14.03	0.67	14.55	4.32	9.58	0.37	15.46	0.18	1143
09/14/01	5:52:36	7.02	0.27	14.06	0.69	14.58	4.34	9.58	0.37	15.46	0.18	1163
09/14/01	6:12:36	7.02	0.27	14.02	0.66	14.56	4.33	9.57	0.36	15.45	0.17	1183
09/14/01	6:32:36	7.02	0.27	14.02	0.66	14.58	4.34	9.58	0.37	15.45	0.17	1203
09/14/01	6:52:36	7.02	0.27	14.02	0.66	14.58	4.34	9.58	0.37	15.45	0.17	1223
09/14/01	7:12:36	7.02	0.27	14.03	0.67	14.56	4.33	9.57	0.36	15.45	0.17	1243
09/14/01	7:32:36	7.01	0.26	14.01	0.65	14.56	4.33	9.56	0.35	15.45	0.17	1263
09/14/01	7:52:36	7.01	0.26	14.02	0.66	14.55	4.32	9.56	0.35	15.44	0.16	1283
09/14/01	8:12:36	7.01	0.26	14.02	0.66	14.56	4.33	9.56	0.35	15.45	0.17	1303
09/14/01	8:32:36	7.01	0.26	14.02	0.66	14.56	4.33	9.56	0.35	15.45	0.17	1323
09/14/01	8:52:36	7.01	0.26	14.02	0.66	14.56	4.33	9.56	0.35	15.44	0.16	1343
09/14/01	9:12:36	7.01	0.26	14.01	0.65	14.56	4.33	9.56	0.35	15.44	0.16	1363
09/14/01	9:32:36	7.01	0.26	14.02	0.66	14.54	4.31	9.55	0.34	15.45	0.17	1383
09/14/01	9:52:36	7.01	0.26	14.03	0.67	14.54	4.31	9.55	0.34	15.44	0.16	1403
09/14/01	10:12:58	7.02	0.27	14.02	0.66	14.54	4.31	9.55	0.34	15.44	0.16	1423

notes:* =Depth to Water

Appendix D – Summary of Quarterly Monitoring Data EMF Site

Changes in TCE Concentrations within Plume Since Remediation Started: On-site wells

well name	location/description	Peak TCE concentration µg/L	Current TCE concentration µg/L (10/29/01)	% Reduction from peak concentration	Other notes
MW-6	upgradient on-site	39	1	97%	
NV-01	source area	1,007,000	60,000	94%	well where TCE NAPL was recovered
MW-8	central plume area	24230	990	96%	
MW-1s	near N. plume edge	195	140	28%	
MW-1d	near N plume edge	3380	150	96%	
NV-2	central plume area	52,000	24,000	54%	well completed to deeper depth in 4/2000
MW-10	near S plume edge	29100	400	99%	
MW-9	central plume	18900	50	100%	
MW-16	central plume	3140	90	97%	
MW-17	central plume	4760	10	100%	
MW-24	central plume	2000	nd	99%	
MW-11s	central plume	1.2	nd	NA	
MW-11d	central plume	2300	nd	99%	
MW-13d	central plume	1200	nd	92%	
MW-12d	North plume limit	nd	nd	NA	
MW-14d	South plume limit	nd	nd	NA	
				Average % Reduction	
				88%	
	mean	82,018	8,583	90%	
	geometric mean	2,795	236	92%	

Changes in DCE Concentrations within Plume Since Remediation Started: On-site wells

well name	location/description	Peak DCE concentration µg/L	Current DCE concentration µg/L (10/29/01)	% Reduction from peak concentration	Other notes
MW-6	upgradient on-site	nd	nd	NA	
NV-01	source area	nd	nd	NA	well where TCE NAPL was recovered
MW-8	central plume area	25200	640	97%	
MW-1s	near N. plume edge	1010	35	97%	
MW-1d	near N plume edge	17600	790	96%	
NV-2	central plume area	18100	11000	39%	well completed to deeper depth in 4/2000
MW-10	near S plume edge	12000	3400	72%	
MW-9	central plume	1350	6	100%	
MW-16	central plume	6610	130	98%	
MW-17	central plume	6180	2900	53%	
MW-24	central plume	27100	2900	89%	
MW-11s	central plume	5300	2800	47%	
MW-11d	central plume	18300	5000	73%	
MW-13d	central plume	27500	3400	88%	
MW-12d	North plume limit	2.6	nd	NA	
MW-14d	South plume limit	1.3	nd	NA	
				Average % Reduction	
				79%	
	mean	11,875	2,750	77%	
	geometric mean	2,735	877	68%	

KCSlip4 44097

SEA410627

Changes in Vinyl Chloride Concentrations within Plume Since Remediation Started: On-site wells

well name	location/description	Peak VC concentration μg/L	Current VC concentration μg/L (10/29/01)	% Reduction from peak concentration	Other notes
MW-6	upgradient on-site	nd	nd	NA	
NV-01	source area	nd	nd	NA	well where TCE NAPL was recovered
MW-8	central plume area	3690	46	99%	
MW-1s	near N. plume edge	113	nd	99%	
MW-1d	near N plume edge	2160	160	93%	
NV-2	central plume area	4220	2500	41%	well completed to deeper depth in 4/2000
MW-10	near S plume edge	2100	400	81%	
MW-9	central plume	430	29	93%	
MW-16	central plume	4140	41	99%	
MW-17	central plume	4190	3300	21%	
MW-24	central plume	15200	770	95%	
MW-11s	central plume	1600	1000	38%	
MW-11d	central plume	2920	2100	28%	
MW-13d	central plume	23100	9000	61%	
MW-12d	North plume limit	nd	nd	NA	
MW-14d	South plume limit	nd	nd	NA	
				Average % Reduction	
				71%	
	mean	5,322	1,759	67%	
	geometric mean	2,605	493	81%	

KCSlip4 44098

SEA410628

BOEING

ELECTRONICS MANUFACTURING FACILITY GROUNDWATER CLEAN-UP

October 2001

Trichloroethene

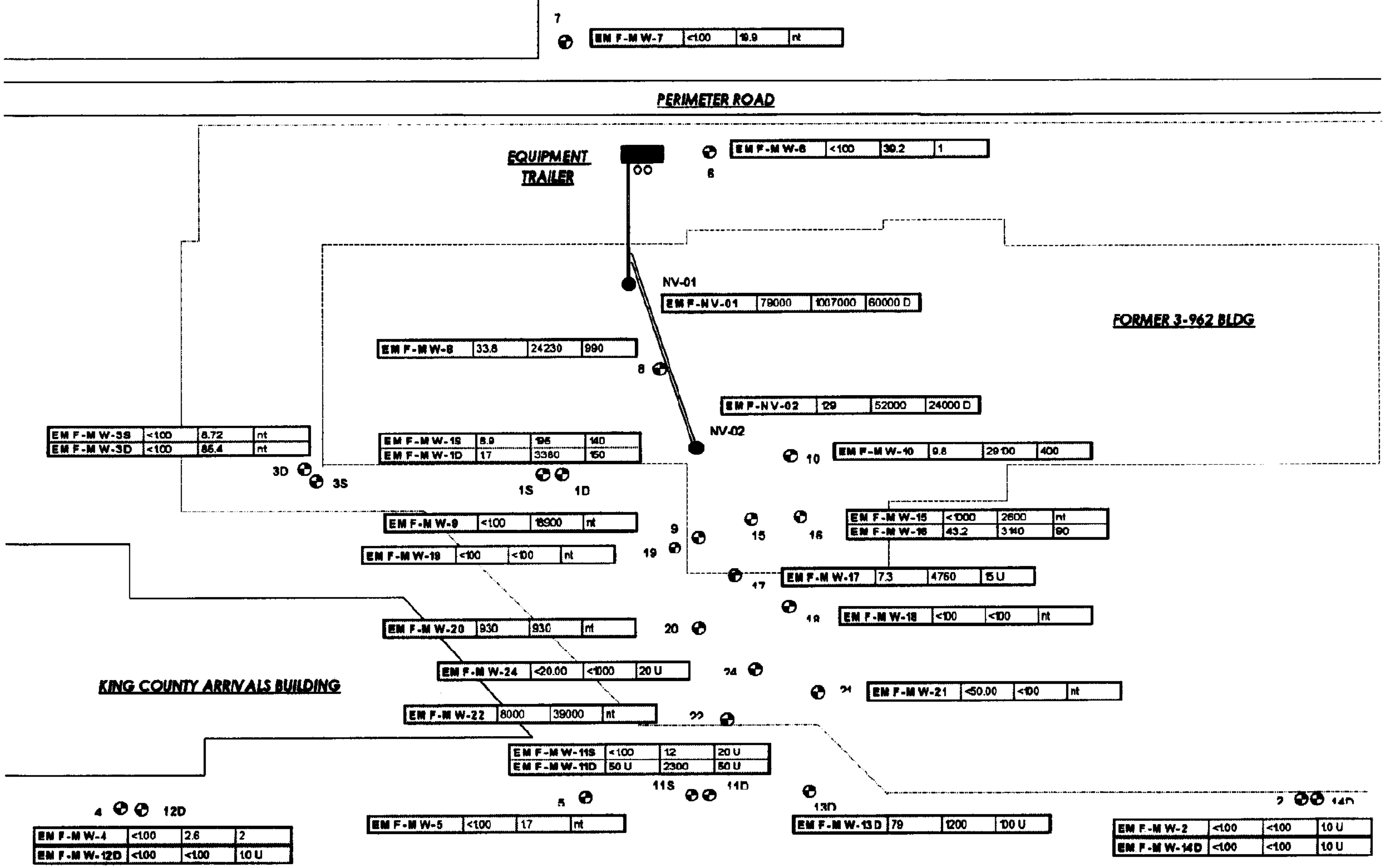
LEGEND

Trichloroethene (µg/l) Clean-up Goal: 2,000 µg/l	PAST LOW	PAST HIGH	Oct-01
EMF-NV-01	79000	1007000	60000 D

LOW - LOWEST DETECTION SINCE JULY 1997 OR WELL INST.
HIGH - HIGHEST DETECTION SINCE JULY 1997 OR WELL INST.

1 MONITORING WELL LOCATION & DESIGNATION
NV-01 TREATMENT WELL LOCATION & DESIGNATION
nt WELL NOT TESTED

0 25 50 75
Approximate Scale in Feet



BOEING

ELECTRONICS MANUFACTURING FACILITY GROUNDWATER CLEAN-UP

October 2001

cis-1,2-Dichloroethene

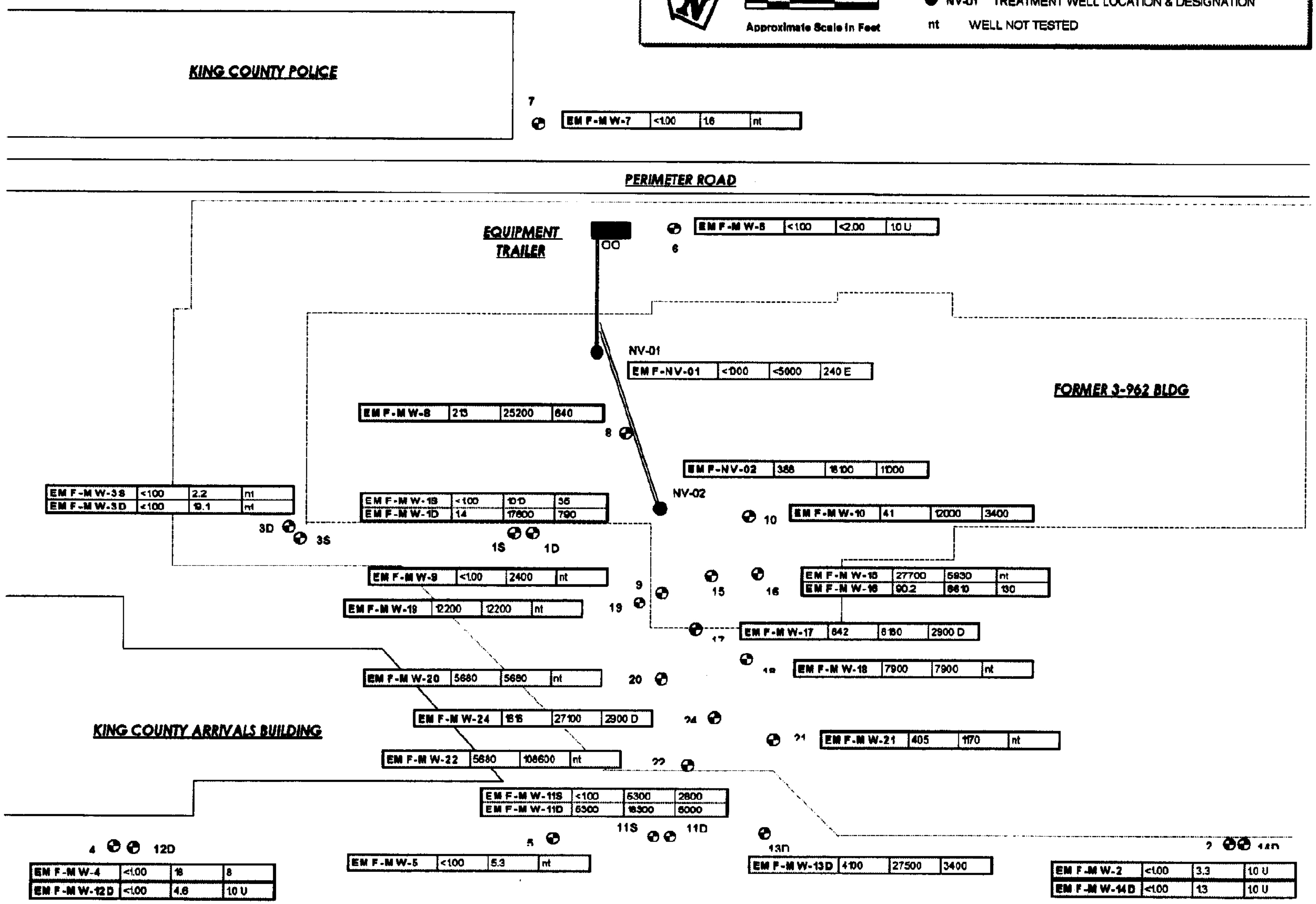
LEGEND

cis-1,2-Dichloroethene (µg/l) Clean-up Goal: 224,000 µg/l	PAST LOW	PAST HIGH	Oct-01
EMF-NV-01	<1000	<5000	240 E

LOW - LOWEST DETECTION SINCE JULY 1997 OR WELL INST.
HIGH - HIGHEST DETECTION SINCE JULY 1997 OR WELL INST.

0 25 50 75
Approximate Scale in Feet

1 MONITORING WELL LOCATION & DESIGNATION
NV-01 TREATMENT WELL LOCATION & DESIGNATION
nt WELL NOT TESTED



BOEING

ELECTRONICS MANUFACTURING FACILITY GROUNDWATER CLEAN-UP

October 2001

Vinyl Chloride

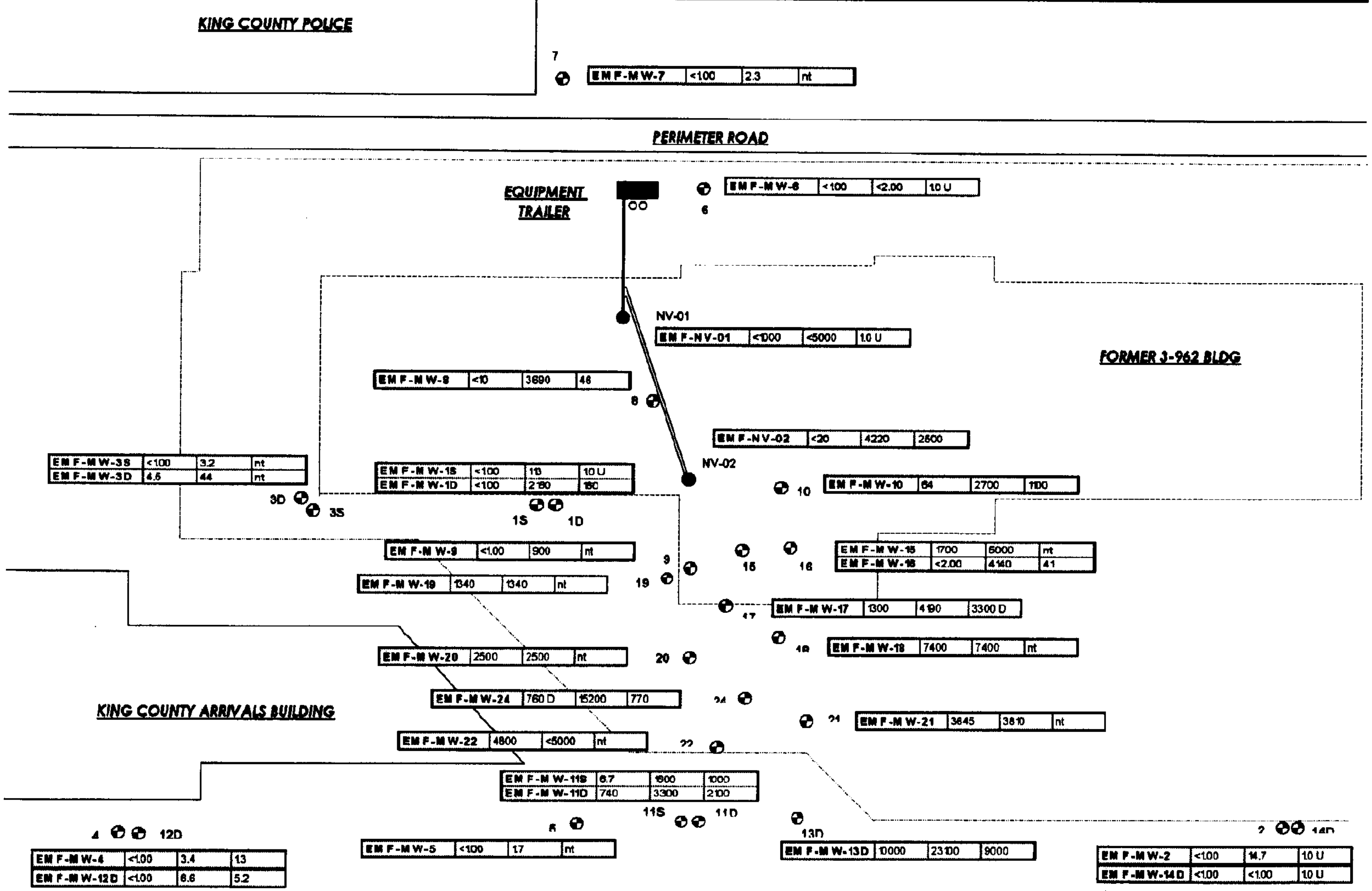
LEGEND

Vinyl Chloride (µg/l) Clean-up Goal: 525 µg/l	PAST LOW	PAST HIGH	Oct-01
EM F-NV-01	<1000	<5000	10 U

LOW - LOWEST DETECTION SINCE JULY 1997 OR WELL INST.
HIGH - HIGHEST DETECTION SINCE JULY 1997 OR WELL INST.

0 25 50 75
Approximate Scale in Feet

1 MONITORING WELL LOCATION & DESIGNATION
NV-01 TREATMENT WELL LOCATION & DESIGNATION
nt WELL NOT TESTED



EMF SITE
SUMMARY OF ANALYTICAL RESULTS
JULY 1997 THROUGH OCTOBER 2001

Trichloroethene (µg/l)
Clean-up Goal: 2,000 µg/l

	Jul-97	Oct-97	Feb-98	May-98	Aug-98	Nov-98	Jan-99	Apr-99	Jul-99	Oct-99	Jan-00	Apr-00	Jul-00	Oct-00	Jan-01	Apr-01	Jul-01	Oct-01
EMF-NV-01	870000	1007000	430000	180000	188000	165000	185000	177800	237000	222000	162000	nt	324000	136400	82800	120000	79000	60000 D
EMF-NV-02	129	652	7500	3160	23800	23100	13000	1700	2120	12800	11600	nt	4800	40600	2525	52000	41000	24000 D
EMF-MW-0																110	nt	nt
EMF-MW-1S	6.9	15.2	40.6	195	84.2	101	67	85	78	77	59.2	91	106	134	125.6	110	100	140
EMF-MW-1D	1.7	29.9	84.5	2.4	<20.00	<10.00	<10.00	169	2200	1638	1416	3380	320	142	219	110	110	150
EMF-MW-2	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	nt	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1	1.0 U	1.0 U
EMF-MW-3S	8.72	5.7	3.8	<1.00	3.5	3.7	4.4	nt	nt	nt	nt	nt	nt	nt	nt	3.5	nt	nt
EMF-MW-3D	85.4	<1.00	1.2	<1.00	<1.00	<1.00	<1.00	nt	nt	nt	nt	nt	nt	nt	nt	1.0	nt	nt
EMF-MW-4	2.3	<1.00	1.9	nt	nt	nt	nt	nt	1.8	2.6	<1.00	<1.00	<1.00	1.6	<1.00	<1	1.5	2
EMF-MW-5	<1.00	1.7	<1.00	<1.00	<1.00	<1.00	<1.00	nt	nt	nt	nt	nt	nt	nt	nt	<1	nt	nt
EMF-MW-6	39.2	38.2	10.7	7.6	6.2	6.3	4.5	3.92	6.1	3.2	1.8	2.1	2.3	1.1	<1.00	1.4	1.2	1
EMF-MW-7	19.9	2.9	5.6	6.4	<1.00	2.4	5.1	nt	nt	nt	nt	nt	nt	nt	nt	1.4	nt	nt
EMF-MW-8	4700 E	7030	114	33.8	50.5	600	2590	420	85	24230	8150	8540	5500	1320	672	650	760	990
EMF-MW-9	17.9	18900 E	<10	<10.00	2	<1.00	<1.00	<1.00	1.2	1.6	1.4	12.7	15.8	5.6	50	710	closed	nt
EMF-MW-10	29100 E	8300	720	147	9.8	<10.00	<10.00	24	12.6	23.6	41	49.8	48	82	90.5	2300	700	400
EMF-MW-11S	Well Installed in June 1998				<1.00	<1.00	<1.00	<1.00	1.1	1.2	<10.00	<10.00	<1.00	<10.00	<10.00	<1	30 U	20 U
EMF-MW-11D	Well Installed in June 1998				747	810	840	2300	670	1310	520	585	<1000	500	<200	59	50 U	50 U
EMF-MW-12D	Well Installed in July 1999								<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1	1.0 U	1.0 U
EMF-MW-13D	Well Installed in July 1999								733	1200	520	675	<1000	<1000	<500	79	100 U	100 U
EMF-MW-14D	Well Installed in July 1999								<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1	1.0 U	1.0 U
EMF-MW-15	Well Installed in April 2000											<1000	2600	nt	nt	nt	nt	nt
EMF-MW-16	Well Installed in April 2000											3140	nt	157	43.2	100	100	90
EMF-MW-17	Well Installed in June 2000												1230	4760	184	250	7.3	15 U
EMF-MW-18	Well Installed in June 2000												<100	nt	nt	nt	nt	nt
EMF-MW-19	Well Installed in June 2000												<100	nt	nt	nt	nt	nt
EMF-MW-20	Well Installed in June 2000												930	nt	nt	nt	nt	nt
EMF-MW-21	Well Installed September 2000													<100	<50.00	nt	nt	nt
EMF-MW-22	Well Installed September 2000													39000	8000	nt	nt	nt
EMF-MW-23	Well Installed September 2000 - Low Production Well															<100	1.2	15 U
EMF-MW-24	Well Installed September 2000													<1000	<20.00	<200	300 D	20 U
EMF-WF-25	West Field Well Installed April 2001															<1.0	1.0 U	1.0 U
EMF-WF-26	West Field Well Installed April 2001															44	54	40
EMF-WF-27	West Field Well Installed April 2001															<1.0	10 U	1.0 U
EMF-WF-28	West Field Well Installed April 2001															<1.0	1.0 U	1.0 U
EMF-WF-29	West Field Well Installed April 2001															1.4	20 U	1.5

EMF SITE
SUMMARY OF ANALYTICAL RESULTS
JULY 1997 THROUGH OCTOBER 2001

cis-1,2-Dichloroethene (µg/l)
Clean-up Goal: 224,000 µg/l

	Jul-97	Oct-97	Feb-98	May-98	Aug-98	Nov-98	Jan-99	Apr-99	Jul-99	Oct-99	Jan-00	Apr-00	Jul-00	Oct-00	Jan-01	Apr-01	Jul-01	Oct-01
EMF-NV-01	<2000	<5000	<10000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	nt	<2000	<2000	<2000	<1000	1500 U	240 E
EMF-NV-02	388	1030 E	6200	4220	15120	15900	9700	5840	3640	11400	18100 E	nt	3000	13100	525	15000	16000	11000
EMF-MW-0																58	nt	nt
EMF-MW-1S	<1.00	1.6	6.6	1010	722	712	543	560	92	108	47.9	38.9	65.4	150	102.2	54	44	35
EMF-MW-1D	1.4	11	171. E	1750	108.6	69	362	2950	5450	4580	9940	17600	1830	776	1060	860	900	790
EMF-MW-2	3.7	2.4	2.3	3	2.4	2.5	1.3	nt	3.3	2.4	1.04	1.6	<1.00	1.2	<1.00	<1	1.0 U	1.0 U
EMF-MW-3S	<1.00	<1.00	<1.00	<1.00	1.1	<1.00	<1.00	nt	nt	nt	nt	nt	nt	nt	nt	2.2	nt	nt
EMF-MW-3D	<20.00	19.1	13.4	10.4	9.4	10	<1.00	nt	nt	nt	nt	nt	nt	nt	nt	3.9	nt	nt
EMF-MW-4	<2.00	1.4	<1.00	nt	nt	nt	nt	nt	3.4	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1	18	8
EMF-MW-5	2.8	3.2	5.3	2.2	2.9	5.7	<1.00	nt	nt	nt	nt	nt	nt	nt	nt	1.7	nt	nt
EMF-MW-6	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1	1.0 U	1.0 U
EMF-MW-7	<1.00	<1.00	<1.00	<1.00	1.6	<1.00	<1.00	nt	nt	nt	nt	nt	nt	nt	nt	<1	nt	nt
EMF-MW-8	213	454	3700	2050	11800 E	15600	13000	6340	1750	25200	9900	5220	2970	1124	927	1200	970	640
EMF-MW-9	116.2	1350	808	25.2	2.8	1.4	4.4	3.9	<1.00	4.8	5.9	147	170.2	37.3	2400	1600	closed	nt
EMF-MW-10	3086	432	8250	1480	353	41	141	95	66.6	126	158.4	246	260	423	333	12000	4100	3400
EMF-MW-11S	Well Installed in June 1998				1.9	58	8.7	<1.00	122	990	89	23	481	350	542	910	5300	2800
EMF-MW-11D	Well Installed in June 1998				6980	8600	7950	11500	5900	18300	11080	8400	7820	15780	10440	7000	5300	5000
EMF-MW-12D	Well Installed in July 1999								2.6	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1	4.6	1.0 U
EMF-MW-13D	Well Installed in July 1999								15500	27500	21000	19550	13600	21400	19850	8400	4100	3400
EMF-MW-14D	Well Installed in July 1999								1.3	<1.00	<1.00	<1.00	<1.00	<1.00	1.1	<1	1.0 U	1.0 U
EMF-MW-15	Well Installed in April 2000											27700	5930	nt	nt	nt	nt	nt
EMF-MW-16	Well Installed in April 2000											6610	nt	792	90.2	310	420 D	130
EMF-MW-17	Well Installed in June 2000												2940	6180	842	1000	1200 D	2900 D
EMF-MW-18	Well Installed in June 2000												7900	nt	nt	nt	nt	nt
EMF-MW-19	Well Installed in June 2000												12200	nt	nt	nt	nt	nt
EMF-MW-20	Well Installed in June 2000												5680	nt	nt	nt	nt	nt
EMF-MW-21	Well Installed September 2000													1170	405	nt	nt	nt
EMF-MW-22	Well Installed September 2000													122000	108600	nt	nt	nt
EMF-MW-23	Well Installed September 2000 - Low Production Well															16000	4800 D	2700 D
EMF-MW-24	Well Installed September 2000													27100	1616	21000	2300 D	2900 D
EMF-WF-25	West Field Well Installed April 2001															1.3	1.0 U	1.0 U
EMF-WF-26	West Field Well Installed April 2001															5600	7200 D	4000 D
EMF-WF-27	West Field Well Installed April 2001															1500	1900 D	1700 D
EMF-WF-28	West Field Well Installed April 2001															<1.0	1.0 U	1.0 U
EMF-WF-29	West Field Well Installed April 2001															1100	1400	980 D

EMF SITE
SUMMARY OF ANALYTICAL RESULTS
JULY 1997 THROUGH OCTOBER 2001

trans-1,2-Dichloroethene (ug/l)

	Jul-97	Oct-97	Feb-98	May-98	Aug-98	Nov-98	Jan-99	Apr-99	Jul-99	Oct-99	Jan-00	Apr-00	Jul-00	Oct-00	Jan-01	Apr-01	Jul-01	Oct-01
EMF-NV-01	<2000	<5000	<10000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	nt	<2000	<2000	<2000	<1000	1500 U	1.8
EMF-NV-02	40.6	42.3	153	170	364	480	310	240	210	290	380	nt	320	<1000	65	1200	1300	900
EMF-MW-0																1	nt	nt
EMF-MW-1S	<1.00	<1.00	<1.00	19.5	<20.00	18	16	17	<10.00	3.4	1.4	<1.00	1.1	2.5	<2.00	<1	1.0 U	1.0 U
EMF-MW-1D	<1.00	<1.00	2.4	14.6	<20.00	<10.00	<10.00	22	<50.00	20.6	24	130	<100	<20.00	<10.00	10	30 U	10 U
EMF-MW-2	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	nt	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1	1.0 U	1.0 U
EMF-MW-3S	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	nt	nt	nt	nt	nt	nt	nt	nt	<1	nt	nt
EMF-MW-3D	<20	1.2	1.1	1.8	1.2	1.5	1.4	nt	nt	nt	nt	nt	nt	nt	nt	<1	nt	nt
EMF-MW-4	<2.00	<1.00	<1.00	nt	nt	nt	nt	nt	2.3	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1	1.0 U	1.0 U
EMF-MW-5	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	nt	nt	nt	nt	nt	nt	nt	nt	<1	nt	nt
EMF-MW-6	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1	1.0 U	1.0 U
EMF-MW-7	<1.00	<1.00	<1.00	<1.00	4.4	<1.00	<1.00	nt	nt	nt	nt	nt	nt	nt	nt	<1	nt	nt
EMF-MW-8	11.5	<200	<100	10.3	<50.00	<100	<100	<100	<50.00	56	<500	30	120	<20.00	<10.00	14	11	12
EMF-MW-9	8.73	<100	21.9	16.8	<1.00	4.2	3.6	5.05	5.4	3.9	3.2	4.2	7.4	<1.00	22	25	closed	nt
EMF-MW-10	160	<100	<200	25	10	<10.00	11	14	10.6	10.9	8.4	9.6	<10.00	<5.00	18	630	250	160
EMF-MW-11S	Well Installed in June 1998				<1.00	1.6	<1.00	<1.00	6.9	30.1	<10.00	<10.00	19.9	<10.00	<10.00	34	230	100
EMF-MW-11D	Well Installed in June 1998				510	800	520	940	630	1340	740	650	1040	<200	1680	1200	1200	1100
EMF-MW-12D	Well Installed in July 1999								1.3	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1	1.0 U	1.0 U
EMF-MW-13D	Well Installed in July 1999								1430	2290	1460	1525	1600	<1000	2250	870	950	1100
EMF-MW-14D	Well Installed in July 1999								<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1	1.0 U	1.0 U
EMF-MW-15	Well Installed in April 2000											2400	1800	nt	nt	nt	nt	nt
EMF-MW-16	Well Installed in April 2000											300	nt	<10.00	8.2	20	30	19
EMF-MW-17	Well Installed in June 2000												380	<200	486	250	420 D	780
EMF-MW-18	Well Installed in June 2000												550	nt	nt	nt	nt	nt
EMF-MW-19	Well Installed in June 2000												720	nt	nt	nt	nt	nt
EMF-MW-20	Well Installed in June 2000												380	nt	nt	nt	nt	nt
EMF-MW-21	Well Installed September 2000													<100	245	nt	nt	nt
EMF-MW-22	Well Installed September 2000													<5000	12800	nt	nt	nt
EMF-MW-23	Well Installed September 2000 - Low Production Well															1200	400 D	540
EMF-MW-24	Well Installed September 2000													<1000	612	1600	330 D	730
EMF-WF-25	West Field Well Installed April 2001															<1.0	1.0 U	1.0 U
EMF-WF-26	West Field Well Installed April 2001															250	440	210 D
EMF-WF-27	West Field Well Installed April 2001															22	44	38
EMF-WF-28	West Field Well Installed April 2001															<1.0	1.0 U	1.0 U
EMF-WF-29	West Field Well Installed April 2001															15	20 U	16

EMF SITE
SUMMARY OF ANALYTICAL RESULTS
JULY 1997 THROUGH OCTOBER 2001

Vinyl Chloride (µg/l)

Clean-up Goal: 525 µg/l

	Jul-97	Oct-97	Feb-98	May-98	Aug-98	Nov-98	Jan-99	Apr-99	Jul-99	Oct-99	Jan-00	Apr-00	Jul-00	Oct-00	Jan-01	Apr-01	Jul-01	Oct-01
EMF-NV-01	<2000	<5000	<10000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000	nt	<2000	<2000	<2000	<1000	1500 U	1.0 U
EMF-NV-02	<20	97.2	312	352	554	740	920	790	1154	2470	4220	nt	240	1010	60	2200	2000	2500
EMF-MW-0																<1	nt	nt
EMF-MW-1S	<1.00	<1.00	<1.00	13.6	<20.00	60	113	53	<10.00	54.2	30.5	7.1	14.5	25.6	15.4	<1	1.0 U	1.0 U
EMF-MW-1D	<1.00	2.4	18.5	561	944	328	626	1260	795	1004	2160	2050	480	302	281	160	140	160
EMF-MW-2	2.2	2.7	5.9	7.1	8	7	7.6	nt	10.4	14.7	10.3	7.5	<1.00	1.1	<1.00	<1	1.0 U	1.0 U
EMF-MW-3S	<1.00	<1.00	<1.00	3.2	<1.00	<1.00	<1.00	nt	nt	nt	nt	nt	nt	nt	nt	<1	nt	nt
EMF-MW-3D	<20	4.5	41.3	7.9	13.4	12.9	14.4	nt	nt	nt	nt	nt	nt	nt	nt	44	nt	nt
EMF-MW-4	<2.00	<1.00	<1.00	nt	nt	nt	nt	nt	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1	3.4	1.3
EMF-MW-5	1.7	1.2	1.4	<1.00	1.2	1.2	<1.00	nt	nt	nt	nt	nt	nt	nt	nt	1	nt	nt
EMF-MW-6	<2.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1	1.0 U	1.0 U
EMF-MW-7	<1.00	<1.00	<1.00	<1.00	2.3	<1.00	<1.00	nt	nt	nt	nt	nt	nt	nt	nt	<1	nt	nt
EMF-MW-8	<10	<200	<100	30.4	610	2690	3690	1580	600	2700	2350	850	670	200	387	410	94	46
EMF-MW-9	12.74	<100	430	195	<1.00	<1.00	6.5	2.63	<1.00	4.3	28.9	107	180.6	56.2	900	480	closed	nt
EMF-MW-10	322	<100	1120	2100	755	94	334	154	64	114	156.6	188	199	212	223	2700	1200	1100
EMF-MW-11S	Well Installed in June 1998				6.7	102	16.6	2.5	164	329	153.2	67	176	209	527	490	1600	1000
EMF-MW-11D	Well Installed in June 1998				740	870	1730	1050	580	3720	2060	1075	2200	1640	2920	3300	2400	2100
EMF-MW-12D	Well Installed in July 1999								3.6	<1.00	2.1	<1.00	<1.00	<1.00	<1.00	<1	6.6	5.2
EMF-MW-13D	Well Installed in July 1999								11900	23100	21600	16650	14400	14700	16300	10000	13000	9000
EMF-MW-14D	Well Installed in July 1999								<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1	1.0 U	1.0 U
EMF-MW-15	Well Installed in April 2000											1700	5000	nt	nt	nt	nt	nt
EMF-MW-16	Well Installed in April 2000											4140	nt	456	<2.00	180	220 D	41
EMF-MW-17	Well Installed in June 2000												4190	2660	1340	1300	1600 D	3300 D
EMF-MW-18	Well Installed in June 2000												7400	nt	nt	nt	nt	nt
EMF-MW-19	Well Installed in June 2000												1340	nt	nt	nt	nt	nt
EMF-MW-20	Well Installed in June 2000												2500	nt	nt	nt	nt	nt
EMF-MW-21	Well Installed September 2000													3810	3645	nt	nt	nt
EMF-MW-22	Well Installed September 2000													<5000	4800	nt	nt	nt
EMF-MW-23	Well Installed September 2000 - Low Production Well															6800	1600 D	690
EMF-MW-24	Well Installed September 2000													15200	1466	6500	760 D	770
EMF-WF-25	West Field Well Installed April 2001															120	63	180
EMF-WF-26	West Field Well Installed April 2001															1300	1800	1300 D
EMF-WF-27	West Field Well Installed April 2001															1300	1700	1400 D
EMF-WF-28	West Field Well Installed April 2001															20	11	9.4
EMF-WF-29	West Field Well Installed April 2001															2500	2800	2400 D

Appendix E – Summary of First Order Degradation Modeling

Basis for first order Degradation Modeling of VOC plume at EMF site

The basic equation used to represent a first order degradation process is:

$$C(t) = C_o\, e^{-kt} \qquad \text{Eq 1}$$

at the EMF site the concentration at the source has been approximately constant because of the high VOC mass (TCE as a DNAPL). The above first order degradation equation can be transformed from concentration as function of time [C(t)] to concentration as function of position [C (x)]. The downgradient position (x) is equal to the velocity (v) multiplied by the travel time (t).

x = v t

rearranging,

t = x/v, and substituting this into equation 1 yields

$$C(x) = C_o\, e^{-(k/v)x} \qquad \text{Eq 2}$$

By plotting the measured concentrations on a logarithmic scale versus distance on a linear scale the above relationship can be used to determine:

1) if the concentration profile fits a first order degradation model
2) the rate constant for the degradation process.

The field data along with the degradation modeling are shown in Figures 5-3 and 5-4. The field data are the peak plume concentrations detected along several different plume transects. At each transect approximately 15 VOC samples have been collected to define the plume boundaries (transverse dimension and vertical interval) at that locations and the peak value is used in the modeling calibration to derive the degradation rate constants.

The degradation rate constant is determined by a least squares fit of the model predictions to the measured field data. The results indicate a good fit between the field data and the model predictions (an R^2 of 0.98). The estimated half life ($T_{½}$) for the slowest degrading VOC is 19 months. This corresponds to the predicted concentration decreasing by 50% (a factor of 2 reduction) for every 500 feet of travel distance.

Summary of first order degradation modeling with generation of daughter products

C_1 =TCE,	k_1 = 1st order decay constant for TCE,
	MW_1 = Molecular weight for TCE
C_2 =DCE,	k_2 = 1st order decay constant for DCE,
	MW_2 = Molecular weight for DCE
C_3 =Vinyl Chloride,	k_3 = 1st order decay constant for Vinyl Chloride,
	MW_3 = Molecular weight for Vinyl Chloride.

TCE

$d\,C_1/dt + k_1 C_1 = 0$

$C_1 = C_{1,,0} \times \int (-k_1 t)\,dt$

$$C_1 = C_{1,0} \times e^{-\lambda_1 t} \qquad \text{Eq. 3}$$

DCE

$d\,C_2/dt + k_2 C_2 - (k_1 C_1)\,MW_2/MW_1 = 0$

$C_2 = C_{2,0} \times \exp(-k_2 t) + (MW_2/MW_1) \times \int C_1(1-\exp(-k_1 t))dt$

$$C_2 = C_{1,0} \times \frac{MW_2}{MW_1} \times \left[\left(\frac{\lambda_1}{\lambda_2 - \lambda_1}\right) \times e^{-\lambda_1 t} + \left(\frac{\lambda_1}{\lambda_1 - \lambda_2}\right) \times e^{-\lambda_2 t} \right] \qquad \text{Eq.4}$$

Vinyl Chloride

$d\,C_3/dt + k_3 C_3 - (k_2 C_2)\,MW_3/MW_2 = 0$

$$C_3 = C_{3,0} \times \exp(-k_3 t) + (MW_3/MW_2) \times \int C_2[1-\exp(-k_2 t)]dt \qquad \text{Eq. 5}$$

No closed-form solution exists for Equation 5 so the solution is derived by a numerical integration over time.

Appendix F – Evaluation of the Effects of Tidally-induced Mixing in Groundwater Near the Duwamish Waterway.

Evaluation of Tidally Induced Mixing Within Groundwater

Groundwater discharge from the unconfined aquifer to the Duwamish waterway is considered to be an important exposure pathway for chemicals present in groundwater beneath the Plant 2 site. The potential impacts to the surface water body are evaluated through comparison of the groundwater discharge concentrations with appropriate criteria developed to protect the surface water resource. The surface water criteria typically consider water quality standards necessary to meet the sediment quality criteria, Ambient Water Quality Criteria (AWQCs) for protection of sensitive aquatic life, and potential human exposure through bioaccumulation in fish and subsequent human ingestion of fish. The MTCA specifically states that the dilution within the surface water body should not be considered when setting cleanup standards for protection of surface water. This is a conservative approach taken by Ecology to ensure that specific discharge locations do not create local impacted areas (e.g., impacts to sediments) and that multiple discharges to a surface water body (when all combined together) do not cause an adverse impact. The same procedures for setting the groundwater cleanup levels are also used in setting the soil cleanup levels with an additional step considering the leaching from soil to groundwater.

A significant amount of research has been completed on the physical and biochemical processes associated with groundwater discharge to tidally influenced surface water. Much of the recent research has been focused on environmental impacts of contaminated groundwater discharging into the Chesapeake Bay. The research projects, including field studies and modeling studies, have clearly demonstrated that the rapidly changing water levels in the inter-tidal zone have a significant impact on the groundwater discharge and the concentration of various contaminants within that discharge. The dispersive nature of the tidally influenced flow regime in groundwater has been recognized for at least 40 years (e.g., see Cooper 1959, Kohout 1960). More recently, several quantitative models have been developed to characterize the chemical transport conditions within the inter-tidal zone (Robinson and Gallagher 1999, Yim and Mohsen ,1992)

Relative to setting groundwater quality standards to protect an adjacent surface water body, one important process is the rapidly changing groundwater movement in the near-shore, tidally-active region of the aquifer. The tidally-active region of the unconfined aquifer is the zone where the water table elevation is influenced by the tide. The inland extent of the tidally-active region varies with the hydrogeological properties of the aquifer. The tidally-active region of a typical unconfined aquifer in the Duwamish area is expected to extend inland about 100 to 200 feet (30 to 60 meters) from the shoreline. In this region of the aquifer, groundwater flow is dominated by the tidal fluctuations of the adjacent (and connected) surface water body. The tidal conditions in the surface water create fluctuating water table elevations and corresponding changes in the groundwater velocities (the changes are both in magnitude and direction).

For the typical conditions of the Duwamish area, the expected range of fluctuating groundwater flow velocities in the inter-tidal zone is shown in Figure 1. The peak groundwater flow velocities in the inter-tidal zone are more than an order of magnitude greater than the typical groundwater flow velocities caused by the regional gradient (up to about a factor of 50 times larger).

This is important because the flux of water in the inter-tidal zone is therefore more than an order of magnitude larger than the flux associated with the ambient groundwater flow (i.e., that induced by the regional gradient). The significantly higher water flux in the inter-tidal zone is comprised of in-flowing water (from the surface water into the aquifer) on the flood tide (high tide cycle) and discharging water on the ebb tide (low tide cycle). This mixing of tidally induced groundwater flow with the ambient groundwater discharge has an important impact on the concentration of chemicals present in the discharged water. If one assumes that the chemical concentrations in the surface water are very low (or zero), then the effect of the tidal mixing within the inter-tidal zone is to significantly dilute the concentrations of dissolved compounds present in groundwater prior to the point where they are discharged to the waterway.

In relation to setting site cleanup levels, consideration of the mixing within the inter-tidal zone may establish significantly higher cleanup levels in groundwater and soil that are protective of the applicable criteria for the surface water body. The total mass flux of chemicals in the groundwater discharge is the same in either case but the mixing in the inter-tidal zone dilutes the concentration and the diluted concentration is discharged at a higher water flux rate. In order to quantify the expected magnitude of the tidally induced dilution at the Plant 2 site a model of the important transport processes was developed based on the analytical methods described by Kim and Mohsen (1992).

Model Description

The model for analyzing the magnitude of the tidally induced dilution is based on the standard advection-dispersion equation used for evaluating transport in porous media. The one-dimensional form of the transport equation is:

$$\frac{\partial}{\partial x}\left(D\frac{\partial C}{\partial x}\right)-\frac{\partial(VC)}{\partial x}=\frac{\partial C}{\partial t} \qquad \text{Eq. 1}$$

where, the dispersion coefficient D is defined as;

$$D=\alpha|V| \qquad \text{Eq. 2}$$

and the symbol α (alpha) is the longitudinal dispersivity. The important consideration in solving Equation 1 for the inter-tidal zone is the fact that the velocity is constantly changing over space and time. In addition, the changing velocity also changes the magnitude of the dispersion coefficient, as shown in Equation 2. These two considerations require that the analysis be developed as a numerical solution because no analytical solution to Equation 1 exists for time and spatially variable velocities.

The expected flow field from the tidal boundary condition is generated based on a simple equation representing the tidal influence as a sinusoidal function. The tidal influence on the groundwater elevation is represented as :

$$h(x,t)\ =h_o\exp(-x\beta)\sin\left(\frac{2\pi t}{t_0}-x\beta\right) \qquad \text{Eq. 3}$$

where;

$h(x,t)$ is the water table elevation (L)
h_o is the tidal amplitude (L)

x is the distance from the tidal interface (L)
t is the time (T)
t_o is the tidal period (T)
and β is a term that defines aquifer properties (1/L)

The term β is defined as:

$$\beta = \sqrt{\frac{\pi S}{t_o T}} \qquad \text{Eq. 4}$$

where:

S is the specific yield of the aquifer (L^3/L^3)
T is the transmissivity of the aquifer (L^3/L-T)

T is calculated as the product of the hydraulic conductivity, K, and the aquifer thickness, B. This is a common equation that has been widely used in groundwater hydrology for representing tidal influences in aquifers. The groundwater velocity at any point is equal to the sum of the velocity due to the regional gradient, V_t, and the oscillating velocity due to the tidal effects, V_o:

$$V = V_o + V_t \qquad \text{Eq. 5}$$

The oscillating velocity component of groundwater flow is derived by differentiation of Equation 3 to get the gradient and applying Darcy's law. The tidal component of the groundwater velocity can be expressed as:

$$V_o = h_o \frac{K}{n_e} \beta \exp(-x\beta)\sqrt{2} \sin\left(\frac{2\pi t}{t_0} - x\beta + \frac{\pi}{4}\right) \qquad \text{Eq. 6}$$

where:

K is the hydraulic conductivity (L/T)
n_e is the effective porosity (L^3/L^3)

Model Application

A series of model simulations of groundwater discharge to typical tidal systems were conducted. The first two simulations are taken from the examples provided Yim and Mohsen (1992) to verify that the model is developed and working correctly (these examples do not apply to the Duwamish specifically but are included to demonstrate that the model works correctly). Figures 2 and 3 illustrate model results for the example cases provided by Yim and Mohsen (1992). Figure 2 shows the base case concentration profile without the tidal boundary condition. Figure 3 shows the concentration profile including the effect of the dispersion induced by the tidal boundary condition. The results compare favorably with the simulation examples provided in the reference paper (Figures 4 and 5 from Yim and Mohsen, 1992)

The model was then applied to a typical example that might be expected for the Plant 2 site. For this example case the following modeling parameters/boundary conditions have been used:

- The boundary condition at upland source area is fixed at a concentration of 10 ppm (this represents an large chemical inventory in soil or groundwater at this location, a worst case example)
- The boundary condition at the waterway discharge is set at waterway concentration (assumed to be 0) on the flood tide and set to a zero gradient (which allows flux out) on the ebb tide
- Aquifer thickness of 30 feet
- Hydraulic gradient of 0.003 ft/ft
- Hydraulic conductivity of the soil at 28 ft/day (10^{-2} cm/s)
- Porosity of soil at 0.25
- Tidal amplitude of 3 feet
- Tidal period of 0.52 days
- Longitudinal dispersivity of 10 ft (typically estimated at 0.1 times the plume travel distance)

Figure 4 shows the model predicted results for the base case with no tidal influence. As expected, the concentration front migrates to the discharge point and ultimately reaches the fixed concentration present at the up gradient boundary.

Figure 5 shows the model predicted results for the base case including the tidal mixing within the inter-tidal zone. The results indicate that the tidal fluctuation has a very significant impact on the concentration of dissolved species discharging from the aquifer to the surface water body. The discharge concentration in the zone near the surface water body is significantly reduced when compared to the results presented in Figure 4. The dilution in the inter-tidal zone induced by tidal mixing appears to be at least a factor of 50 for the cases examined.

The same analysis can be used to predict the salinity profile within groundwater induced by the tidal mixing. In this case the groundwater is assumed to have a background salinity of 0.0 and the tidal boundary has a salinity of 35 parts per thousand (ppt). This is typical of salt water but may be somewhat higher than this part of the Duwamish. The predicted salinity profile in the inter-tidal zone is shown in Figure 6. The relation between salinity intrusion at a specific point and corresponding dilution of chemicals in discharging groundwater is linear. Therefore, measurement of a salinity profile may be used as quantitative proof of the mixing processes in the inter-tidal zone.

Calibration to observed water table fluctuations and the induced salinity profile within groundwater should be considered to verify/calibrate the modeling results. Ideally, data would be collected from two or more wells located relatively near the shoreline and include water levels fluctuations salinity measurements. Based on the predicted salinity profile, the two measurement points should be within about 50 feet of the waterway. These type of data, coupled with the modeling analysis, may be useful in setting site-specific cleanups levels for the Plant 2 site and demonstrating that the cleanup levels are protective of the relevant exposure pathways in the surface water body.

References

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Kohout, F.A .,1960. Cyclic flow of salt water in the Biscayne aquifer of southeastern Florida. *Jou. of Geophysical Research*, vol 60, no. 7, pp 2133-2141

Robinson M.A. and D. Gallagher, 1999. A model of groundwater discharge from an unconfined coastal aquifer. . *Gound Water*, vol 37, no. 1, pp 80 -87.

Yim, Y.S. and M. Mohsen 1992. Simulation of tidal effects on contaminant transport in porous media. *Gound Water*, vol 30, no. 1, pp 78-86.

Figure 1. Tidally Induced Groundwater Flow Velocities

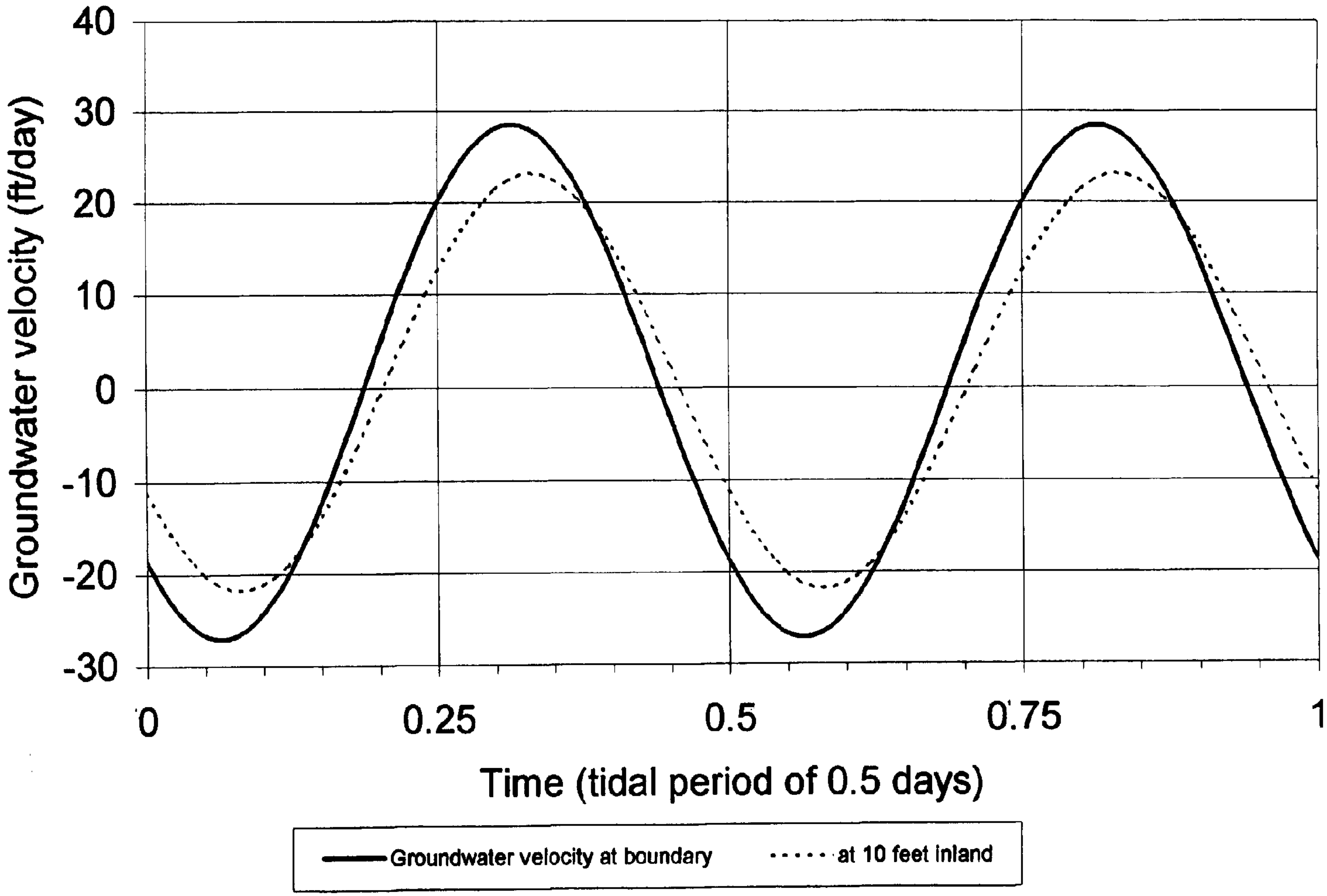

Figure 2. Example Case of Plume Movement Without Tide, Yim and Mohsen 1992

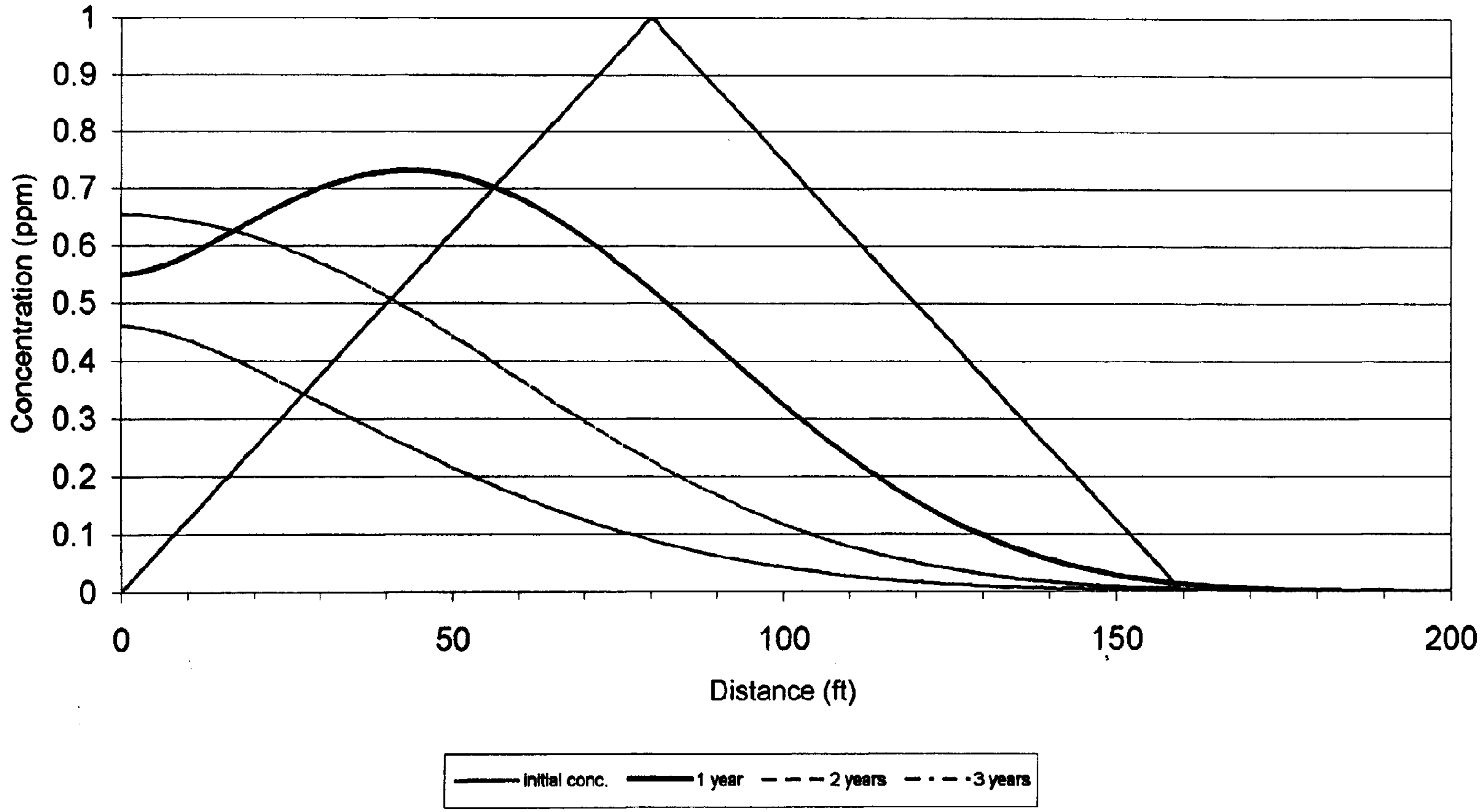

Figure 3 . Example Case of Plume Movement With Tide, Yim and Mohsen 1992

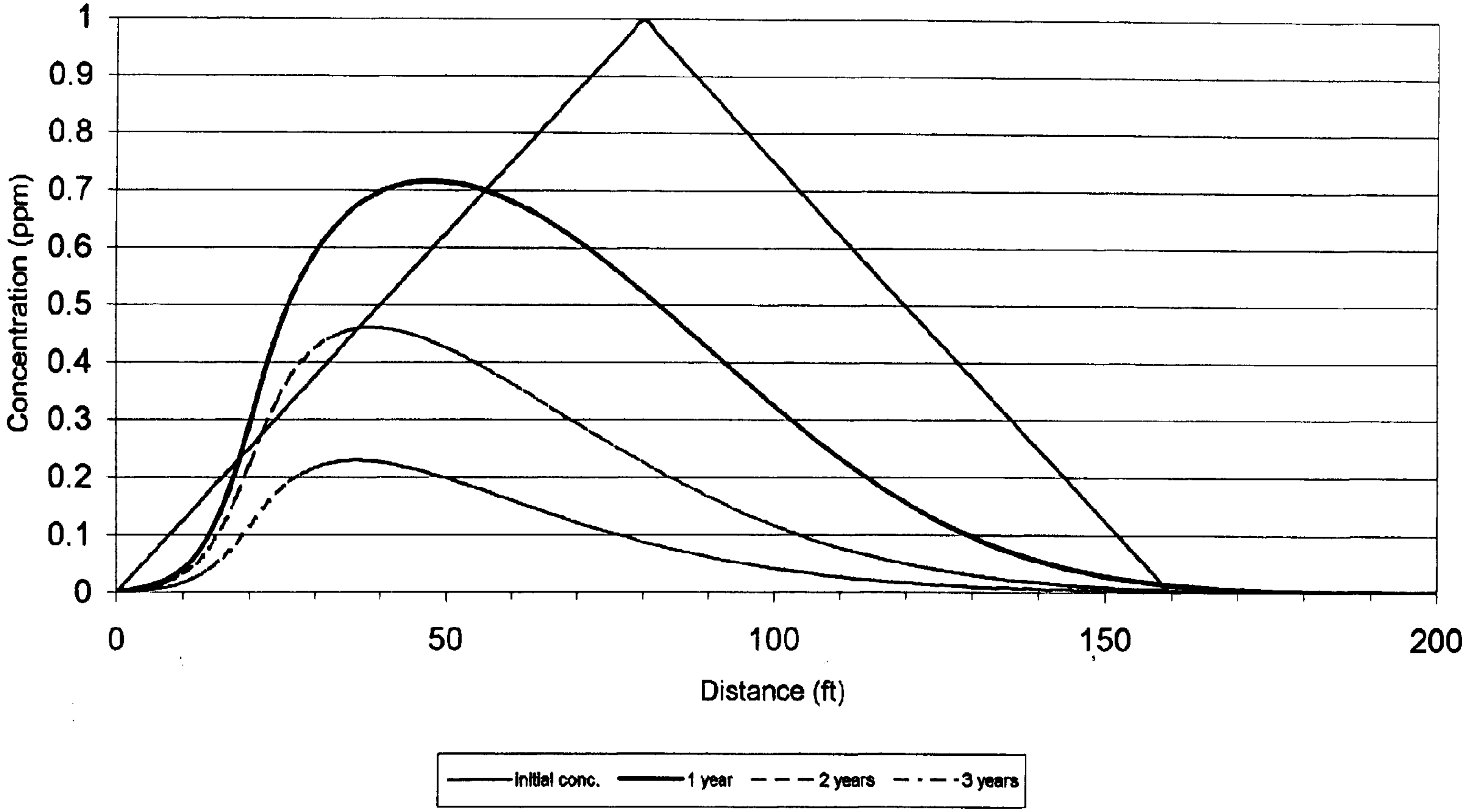

Figure 4. Example Case of Plume Movement in Unconfined Duwamish Aquifer Without Tide

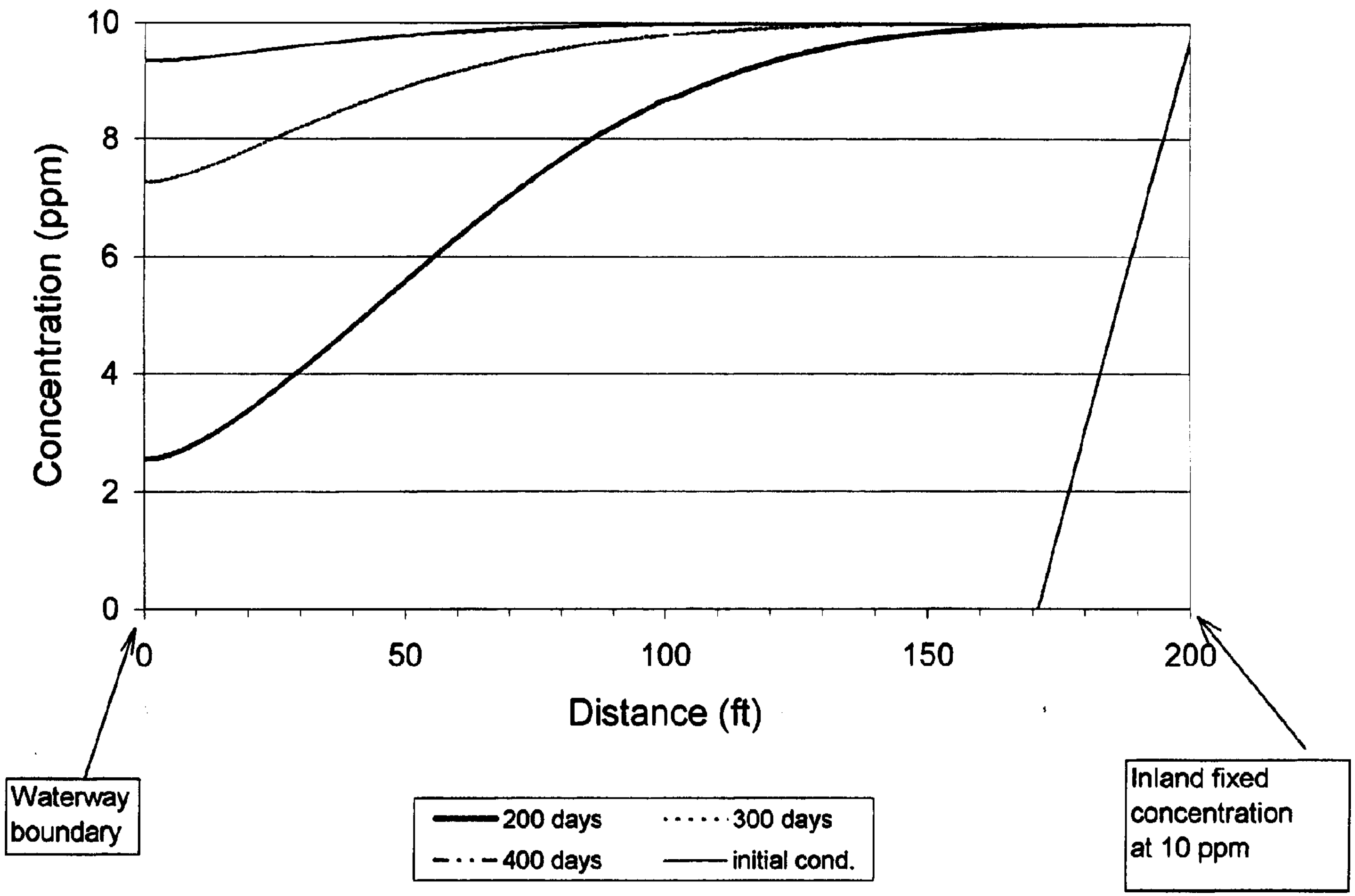

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Figure 5. Example Case of Plume Movement in Unconfined Duwamish Aquifer With Tide Influence

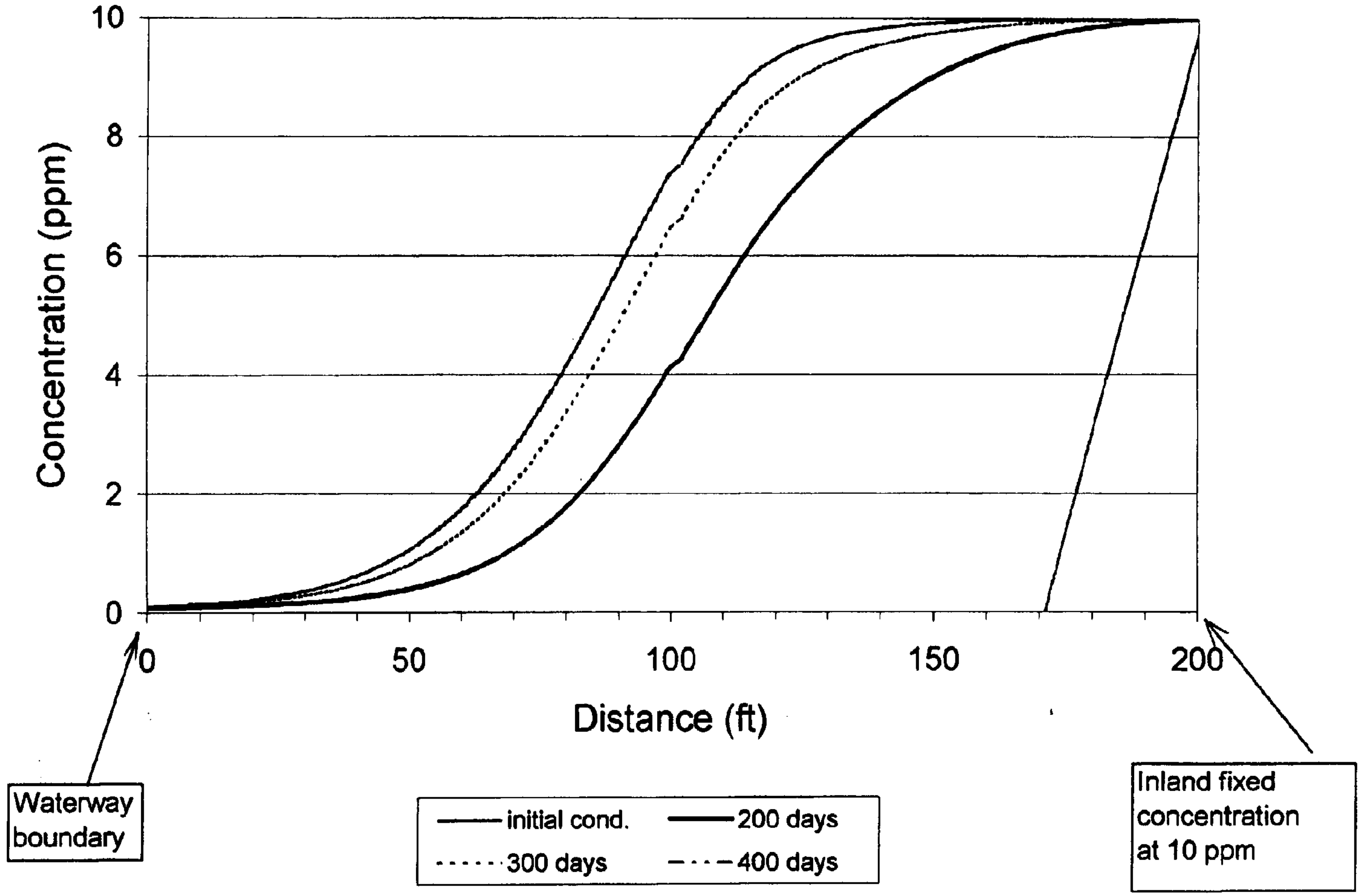
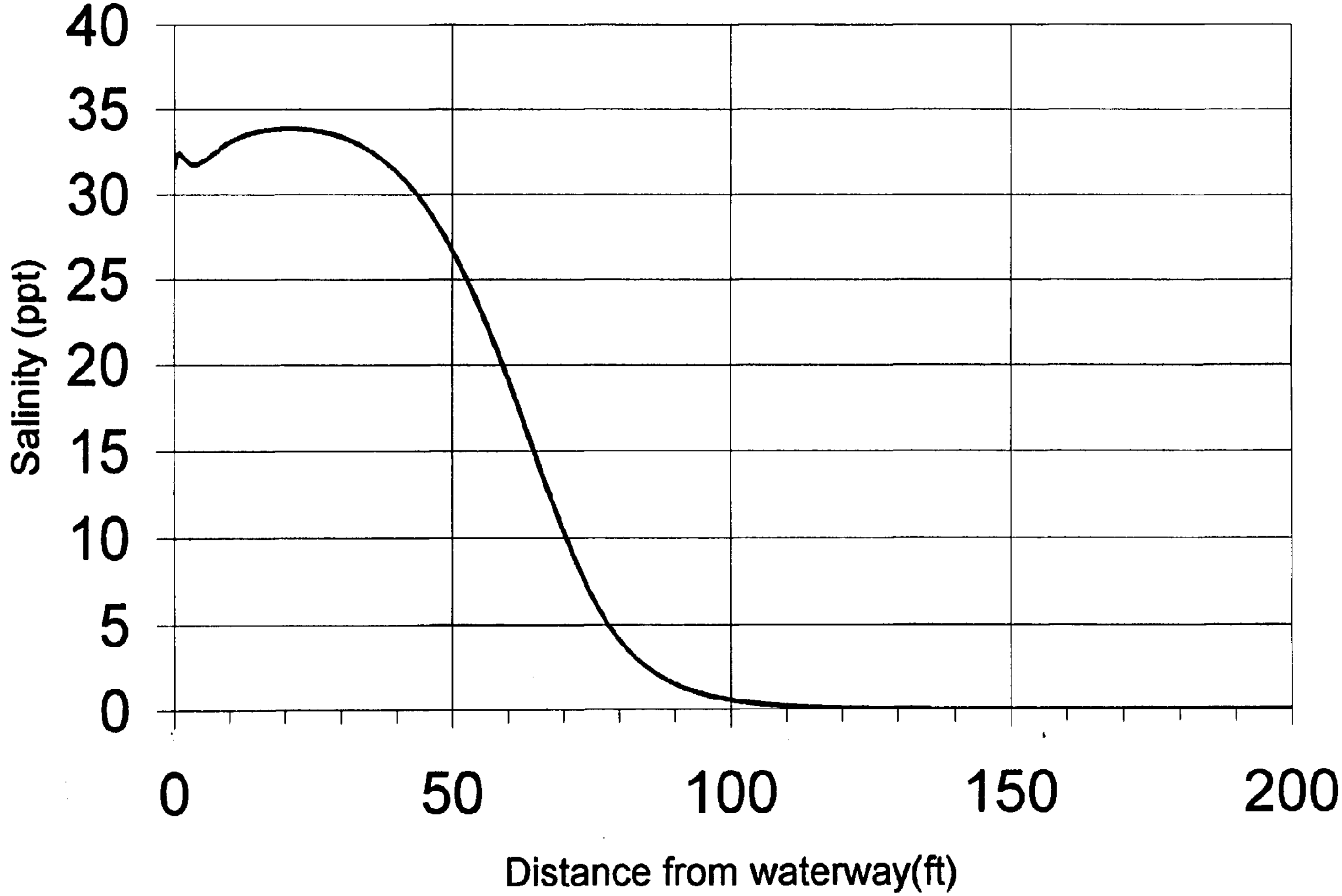


Figure 6. Model Predicted Salinity Intrusion at Plant 2 Site



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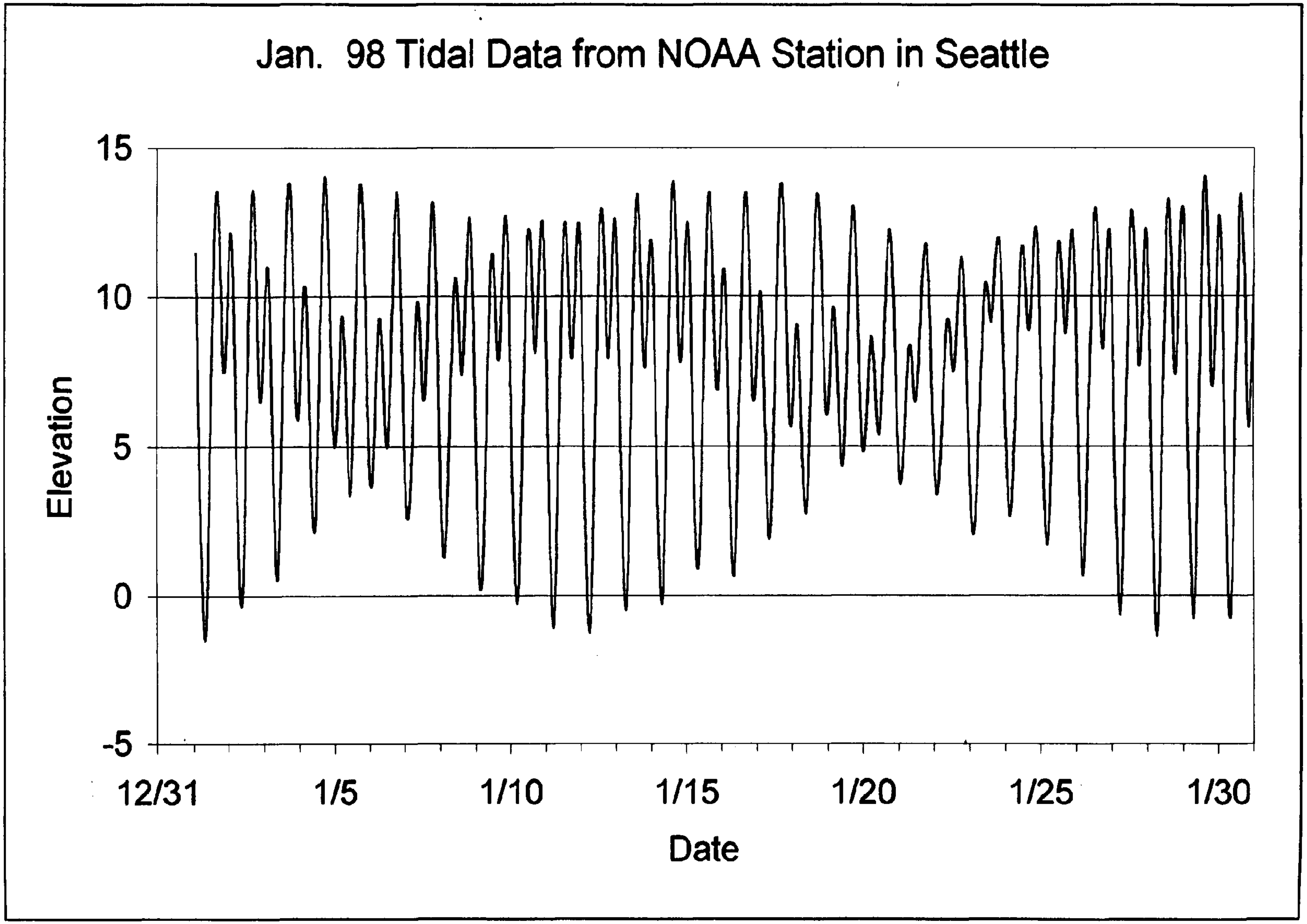
Jan. 98 Tidal Data from NOAA Station in Seattle
15
10
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0
-5
Elevation
12/31
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Date